MORRIS MAGNETICS

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PALEOMAGNETIC STUDIES
GROUND MAGNETIC SURVEYS
ROCK MAGNETIC ANALYSES
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RECEIVED
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Ans'd.

CANMET
Mineral Technology Branch,
555 Booth Street,
Ottawa, Canada
K1A 0G1

Attention : Dr. R. Molnar

Feb 10 1988

Dear Dr. Molnar

Please find enclosed a completely revised version of our report on the correlation between magnetic property variations and lithological variations in three cores from the Waite - Amulet Tailings. I have specifically included new sections on: an abstract, an introduction section, and a correlation analysis. Also I have explained the rationale behind the magnetic property measurements. I think you can now find more information on this technique by reference to the book by Thompson and Oldfield on Environmental Magnetism. As far as format is concerned I have used the same format as Jambor and Petruk in their MSL Division reports. I have used a true LQP on the final copy. I trust that everything is now satisfactory. If you require any further changes I would appreciate a quick response.

As I am sure you are aware this contract was intially intended to compare suceptibility profiles in the naturally altered tailings of the Waite - Amulet pond with information we had already gained from our study of theartificially weathered ORF lysimeter experiment. We did not achieve this objective. As stated in the report this can only be achieved if you have the correct samples to perform this type of analysis. With only 6 of 64 samples from the altered zone it is not possible to discuss variations in the altered zone. Given the poor sampling procedures, and the reluctance to provide the true depth positions of these samples until late in the experimental work I feel we have managed to salvage a meaningful report. We have given much more than was required by our contract; our internal costing of this program is over $16K. We have supported this overrun totally internally. We believe that magnetics can make a significant contribution to this program if given a fair chance. To do this we must have access to the the correct samples that are carefully preserved. We now ask that you provide the funding in the next financial year to perform the experimen that we initially intended to perform under this contract.

Yours sincerely,

52pp

Bill Morris

W. A. Morris

TITLE:

PETROLOGY, SEDIMENTOLOGY, AND CHEMISTRY WAITE AMULET TAILINGS - A CORRELATION WITH MAGNETIC SUSCEPTIBILITY

FINAL REPORT

BY

W. A. MORRIS

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ABSTRACT

Grain size and chemical analyses of 64 specimens from cores WA2, WA20 and WA22 from the Waite - Amulet tailings pile indicate that the observed magnetic property variations are mainly the result of the primary lithological differences. Only 6 of the 64 samples were collected from the near surface zone of secondary altered tailings. While it was possible to use the magnetic property data to recognise the boundary of the alteration front, there were insufficient samples to provide any information on the geometry of susceptibility depletion zones in the altered tailings.

Grain size and magnetic mineral content parameters derived from the magnetic property measurements are systematically related respectively to the observed median grain size and calculated sulfide content. On the basis of these observations it can be shown that three magneto-lithological groups identified on the basis of susceptibility and saturation remanence measurements correspond to three distinct tailings lithologies; a) sand grade tailings with significant sulfide content = uniform high SAT REM, and uniform high SUSC, b) silt grade tailings with lesser sulfide content = variable moderate SAT REM and SUSC, and c) clay grade tailings with little or no sulfides = uniform low SUSC and SAT REM.

INTRODUCTION

In most mining operations the desired mineral usually forms only a small percentage of the total mass of the rock mined. Once the target mineral has been extracted much of the resulting waste material is deposited in large tailings ponds. Upon subsequent mine closure the tailings are left to respond to the effects of surficial weathering. When the tailings comprise minerals which are chemically reactive under surface conditions this can lead to the development of environmentally hazardous fluids passing from the tailings containment area to the surrounding countryside. For example, tailings with a high concentration of pyrite (high sulfide tailings) upon oxidation give rise to extremely acidic (pH<3) fluids. It is clearly in the public interest therefore to develop cost effective methods of monitoring, and if possible controlling, the reactivity of these types of tailings.

Laboratory simulations with artificially enhanced weathering rates (the CANMET / ORF lysimeter experiments) have been used to document the chemical changes associated with tailings oxidation. One of the parameters controlling the rate of oxidation is the supply of oxygenated surface water to the tailings. With increasing time the surface water gradually penetrates to deeper levels in the tailings. The degree of toxic buildup therefore is directly related to the volume of tailings that have been oxidised. One approach to quantifying this problem is to measure the current depth of the oxidation front at a number of points in the tailings pile. This can be established by determining the depth at which unaltered tailings are first detected. This is a time consuming process, and cannot be easily applied in the field. Hence, an alternative method of determining the position of the oxidation front is examined in this report. Since oxidation of pyrite, as well as generating sulphuric acid, also leads to the release of significant quantities of iron. It is felt that magnetic parameter methods may provide a possible method for rapid oxidation front mapping.

Vertical and lateral fluid transport directions in the saturated tailings below the water table are calculated by measuring the differences in hydraulic head between piezometers inserted into the tailings. This technique cannot be applied to mapping fluid pathways in the unsaturated tailings above the water table. Yet it is these unsaturated tailings which contribute most to the formation of toxic fluid concentrations. One possible approach to this problem is a rock magnetic approach. As noted above oxidation leads to the release of iron into solution. If this iron rich solution is immobile then the excess iron will be deposited as a coating on the local silicate grains. If however, the iron enriched solution is generated in a zone of locally enhanced flow then the iron will be transported away before grain coating can develop. Magnetically this hypothesis would be characterised by enhanced susceptibility signal in regions of restricted flow, and relatively depleted

signals in regions of enhanced flow.

Tests of these hypotheses have been performed on samples from the artificially weathered tailings of the ORF lysimeter experiment. Unfortunately all the tailings were all located in the unsaturated zone; all the tailings were oxidised. Hence, it was not possible to test whether magnetics could detect the location of the oxidation front. Susceptibility readings on samples from over 40 cores from the ORF lysimeter defined a dendritic pattern of susceptibility depletion. The area of depleted susceptibility increased with depth in the tailings pile, and decreased with distance from the lysimeter outlet. Geochemical experiments confirmed these susceptibility variations correspond to differences in the extent of secondary iron overgrowths. For these artificial tailings then it appears that susceptibility is mapping fluid pathways in the unsaturated tailings.

To test if these rock magnetic techniques could be applied to a natural tailings setting magnetic property measurements were performed on a suite of 64 samples taken from three cores from the Waite - Amulet tailings of Noranda Limited. The three cores (WA-2, WA-20, and WA-22) examined in this study are from the outer edge of the tailings basin (figure 1). After retrieval each core was subdivided into approximately 1 foot long segments, which were then stored in individual plastic bags. The samples for magnetic property analysis were obtained fron these core segments. Unfortunately the effects of transportation, freezing, and subsequent thawing destroyed the primary core structure in most of the core segments. The sub-samples are not representative of any single horizon, rather they represent some mix of the variations present within each 1 foot segment.

When initially received the true depth positions of the individual samples were not provided. Initially then it was not possible to discuss any variations of magnetic property versus depth. It was only possible to examine the data for the presence of any magneto-lithological groupings. On the basis of a comparison between saturation remanence (SAT REM), and susceptibility (SUSC) three such groupings were isolated. From figure 2, the groupings are:

1) uniform high SAT REM, and uniform high SUSC,
2) variable moderate SAT REM and SUSC, and
3) uniform low SUSC and SAT REM.

Three factors contribute to variations of SUSC and SAT REM. These are:

1) total magnetic mineral content,
2) magnetic mineral grain size, and
3) magnetic mineral composition.

Both of the magnetic properties plotted in figure 2 are quoted in terms of c.g.s. units per gram. Any changes in magnetic mineral content represent changes in the concentration of the magnetic minerals. A twofold increase of magnetic mineral content would produce a doubling of both the SAT REM and SUSC values. Distance along the 45° lines on figure 2 represents an increasing concentration of magnetic minerals (compare figure 4.9 page 31, Thompson and Oldfield, 1986). Even on a cursory examination it appears that much of the differences between the individual magneto-lithological groups can be attributed to differences in magnetic mineral content.

A decrease in the average magnetic mineral grain size is usually reflected by an increase in SAT REM, and a decrease in SUSC (see figure 4.9 Thompson and Oldfield, 1986). That is, the ratio SAT REM / SUSC increases for decreasing grain size. Perpendicular distances above and below the 45° line on figure 2 represent changes in magnetic mineral grain size. Taking a simplistic approach it would appear that the samples with higher magnetic mineral concentrations are comprised of have coarser grain size particles.

All the tailings are from the same source material. The extraction process should further act to remove any variations in magnetic mineral compositional fluctuations. Therefore it appears safe to assume that any magnetic oxide compositional variations are minimal.

SCOPE

Magneto-lithological groupings may arise from two consequences;

a) primary magnetic mineral variations caused by sedimentological factors controlling particle transport, and

b) secondary magnetic mineral variations produced as a result of the chemical alteration of near surface tailings.

Based solely on a visual assessment of the samples it was suggested that the three magneto-lithological types correspond to different primary tailings lithologies. It was felt that secondary alteration related oxide mineralogy was only of limited significance. However, in the absence of any depth control on the samples it was difficult to determine which samples represented the near surface alteration environment, or whether magnetically similar samples were from adjacent horizons.

The depth positions have now been received. In this report we will present plots of the magnetic property variations versus depth. These plots will be examined to determine whether the magnetic property techniques presented above can be used in a natural tailings environment to;

a) determine the depth of the oxidation front, and
b) to establish fluid pathways in the altered tailings.

Estimates of the parameters grain size, and concentration derived from magnetic property measurements will be compared to hydrological, chemical, and petrological derived estimates of the same parameters. This will define the response functions of the magnetic parameter to lithological variations in the tailings.

GRAIN SIZE VARIATIONS

Method

The grain size distribution for each sample from the tailings was determined using a combination of hydrometer, and dry sieving techniques. After separation of the +2mm fraction, a weighed portion of tailings was stirred into a measured volume of distilled water. To obtain the content of silt and clay sized particles the suspended solids were well mixed and then allowed to settle; the density of the fluid was measured at a number of specific times. The sand size fraction was determined using a dry sieving technique. The granulometric distribution, the median grain size, and the sorting of each sample was calculated using an algorithm reported by Stewart and Gedlinske (1986).

Results

The results from the granulometric study are summarized in Tables 3, 7 and 11.

Figure 3 presents the granulometric compositional variation of the samples. The greatest majority of the samples consist of sand rich particles. A number of samples also contain variable amounts of silt sized particles. There is a distinct group of samples with >80% silt sized particles. Few samples contain more than 5% clay sized particles. Only two samples comprise more than 50% clay sized particles, and both are from the clay zone at the base of core WA-20. There are five to seven samples which one might loosely group as clay enhanced samples.

The grain size versus depth plots (figures 4 and 5) reveal the following features:

-The tailings sampled by cores WA-20, and WA-22 are formed predominantly of sand sized particles.

-Silt grade particles form the major portion of the tailings in core WA-2.

-The tops of cores WA-2 and WA-20 are marked by zones of enhanced clay content. A similar zone does not appear in WA-22.

-The upper 15 feet of core WA-20 is characterised by a very uniform grain size distribution.

-The base of WA-20 is marked by the presence of two clay zones which are separated by a silt rich horizon.

-Core WA-22 has the least uniform particle size distribution. The upper portion of this core contains two silt horizons within a sequence of increasing sand content

versus depth. The silt content of the lower portion of WA-22 is significantly higher than for the upper portion.

In summary the grain size analysis suggests the presence of three distinct lithological types:

1) sand rich tailings (present in cores WA-20 and WA-22),

2) silt rich tailings (predominant in core WA-2, and locally developed in core WA-22). The silt content is variable.

3) clay rich tailings (present as distinct stratigraphic horizons at the base of cores WA-2 and WA-20).

The clay enriched zones at the top of cores WA-2, and WA-20 do not belong to the category of the clay rich tailings. In these samples, clay forms only a minor portion of the total particle distribution, whereas the category 3 samples are composed primarily of clay sized particles.

PETROLOGY

Introduction

Details of the mineralogical variations in the tailings, especially for core WA-20, have been previously summarised by Petruk and Pinard, and Jambor (both papers in Siwik 1986).

Results

To summarise from Petruk and Pinard's report, "the tailings contain about 60 wt% pyrite and 14 wt% pyrrhotite at 3 feet below the water table, about 25 wt% pyrite and 6 wt% pyrrhotite at the water table, about 5 wt% pyrite and 5 wt% pyrrhotite in the unsaturated zone; both minerals are absent in the near surface zone. These data indicate the alteration of sulphide minerals progresses slowly below the water table, faster in the unsaturated zone, and has been completed near surface."

Our examination of thin sections confirm the results of Petruk and Pinard. In addition we have observed the following:

a) In core WA-20, the near surface zone shows an increase in magnetite content relative to the immediately underlying unaltered tailings. This increase can be attributed to locally enhanced primary deposition, or secondary related enhancement of magnetite. No secondary overgrowths were detected.

b) The clay zones have a much reduced content of opaque minerals relative to the sandy tailings. The opaque content of the clay horizons is comprised of roughly equal amounts of oxide and sulfide minerals, unlike the sands in which pyrite is totally dominant.

Microprobe analyses of the oxide minerals did not reveal any systematic variations of magnetic mineral composition. Magnesium exhibited the widest variation. However, the variation within a single sample was on the same order of magnitude as the variation between samples.

CHEMICAL VARIATIONS

Introduction

The bulk chemical composition of each sample from the tailings was determined by XRF analysis. A specific suite of elements was selected for the tailings. These included Fe, S, Cu, Zn, Co, Cr, V, and Ni. Bulk composition results are summarized in Table 4 (WA-2), Table 8 (WA-20) and Table 12 (WA-22).

Results

Possible correlations between the total iron content and other elemental concentrations were examined. In Figure 6, percent iron is plotted versus other elements (S, Cu, Zn, Pb). We observe a simple twofold relationship between what may be called high and low concentrations of iron in the tailings. The low iron tailings generally have lower concentrations of the other elements. Figure 7(d), a comparison between iron content and median grain size indicates the low / high iron subdivision corresponds to differences in average grain size. It would appear that the high iron tailings are generally of silt, or sand, grade and contain mainly sulfides. The low iron tailings are of clay grade. Neither the high, nor the low, iron tailings appear to show any systematic relationship between total iron content and any other element.

Correlations between the concentrations of S and elements such as Cu and Zn are excellent. For example the correlation between Cu and S yields a percentage fit of 84.6%. However, as indicated in figures 7(a) and 7(b) there are some specimens which have quite divergent values. These divergences may arise from either depletion, or enhancement, of S, Cu and/or Zn.

Figure 8 (a-c) shows the bulk compostion concentrations for each element plotted versus depth. The chemical data serve to identify three distinct lithological types:

1) The near surface zone. This zone is typified by the depletion of Cu, and Zn; Fe and S may be either enhanced or depleted. All of the cores appear to show a Cu enrichment zone immediately beneath this near surface zone.

2) The main body of the tailings. This unit has relatively uniform levels of Fe content. Cu, Zn and Pb are substantial throughout this main unit. Locally enhanced zones of Pb (e.g. WA-

20) are suggestive of placer concentrations.

3) Clay rich units. These zones are characterised by very low contents of all of the elements measured by this XRF study. It would appear these samples are mainly formed of silicate grains.

The redox state of the iron in each tailings sample provides information on the dominant iron mineral present in that portion of tailings (Studemeister 1983). Differences in redox state may be expected from primary depositional effects. Both the petrological studies, and the bulk chemical analyses indicate the enhanced presence of oxides in the clay rich tailings relative to the dominant sulfide content of the sand and silt grade tailings. Chemical alteration of the tailings involves the degradation of mainly pyrite, with subsidiary pyrrhotite to produce species of the general form iron hydroxide, iron carbonate, or iron sulphate. These species can either be deposited on the surface of the tailings particles, or can be flushed from the tailings to be deposited later in the tailings effluent pond. Column C in Table 6 reports the ratio Fe^{2+} / Fe Total for a number of samples from WA-20. Three distinct levels of oxidation index (OR) are apparent:

1) the uppermost zone (top two samples) have an OR value around 0.20. The next sample (15) just 0.45 feet lower has an OR value of 0.11.

2) the main bulk of the tailings is characterised by OR values ranging from 0.06 to 0.11.

3) the clay zones at the base of the tailings have OR values ranging from 0.39 to 0.49, values which are significantly higher than any of the other zones in WA-20.

SUMMARY OF PHYSICAL AND CHEMICAL PROPERTIES

As stated at the outset, parameter variations in the tailings can be attributed to two causes. First, there are primary depositional effects, and second, there are secondary chemical alteration related effects. In summary the grain size, petrology, and chemical studies identify the following zones:

1) An uppermost alteration lithology characterised by:
   -clay particle enhancement.
   -depletion of Cu, Zn.
   -an enhanced Cu zone generally underlies the depleted zone.
   -Fe and S may be either substantially enhanced, or depleted.
   -iron oxide particles are predominant in reflected light.

2) An unaltered tailings unit characterised by:
   -average particle size may be either of silt, or sand grade.
   -sulphides in higher concentrations than oxides.
   -sulfide content is greater in the sand grade tailings.
   -Fe content is independent of grain size, or other elements.
   -Cu, Zn and S exhibit a systematic correlation.

3) A clay sized particles dominant unit characterised by:
   -dominance of clay sized particles.
   -low to negligible contents of S, Cu, Pb, and Zn.
   -reduced Fe content.
   -equivalence of sulfides and oxides in polished thin section.

Of the 64 samples examined in this study only 6 show petrological and chemical indications of belonging to the zone of altered tailings. The extent of the alteration zone as defined by these samples is less than that reported by Jambor (1987) based on the presence of sulfate. The significance of this discrepancy is not known. The majority of the samples in this collection are from unaltered tailings.

MAGNETIC PROPERTY VARIATIONS

Three separate magnetic properties were measured:

a) Magnetic Susceptibility (SUSC) - the magnetisation induced in a sample by a small direct magnetic field. This magnetisation disappears when the induced field is removed.

b) Saturation Remanence (SAT REM) - the remanent magnetic field remaining in a specimen after exposure to a direct magnetic field of at least 10 kOe. Remanent magnetisation can be measured once the applied field has been removed.

c) Saturation Remanence (200) (SAT REM-200) - the remanent magnetic field remaining in a specimen after an applied direct field of 200 Oe is given to the specimen in opposition to the saturation field. Again this is measured after the applied field has been removed.

If we assume there are no significant variations in magnetic mineral composition then from these measurements we can calculate two ratios which provide diagnostic information on the status of the magnetic oxides present in a sample:

1) SAT REM + SUSC Distance

In this ratio we emphasize the oxide mineral content in a sample. As noted earlier a doubling of oxide mineral content corresponds to a doubling of both SUSC and SAT REM. Hence if we calculate the relative distance of samples along a line at 45° degrees from the origin this will give a direct measure of the total oxide content in the sample.

2) SAT REM / SUSC Ratio

This ratio removes the effect of oxide mineral content, and emphasizes the effects of oxide mineral grain size. The basis of this observation is that SUSC decreases with decreasing grain size, while SAT REM increases with increasing grain size. Hence an increase in the ratio SAT REM / SUSC. corresponds to a decrease in the effective oxide grain size. Hence if we calculate the relative distance of each point above or below a 45° line passing through the origin this will give a direct measure of oxide grain size.

Results

Details of the magnetic property variations present in these core are reported in Tables 1, 2, 5, 6, 9, and 10.

Plots (figure 9a-c) of magnetic property variations versus

depth show the following features:

For WA-2:
-a near surface zone of reduced SUSC, SAT REM and SAT REM-200.
-an intermediate zone of enhanced SUSC and SAT REM, and uniform SAT REM-200.
-a basal zone of low SUSC, low SAT REM, and low SAT REM-200.

For WA-20:
-a surface zone of enhanced SUSC, SAT REM and SAR REM-200.
-an intermediate zone of constant SAT REM, SUSC, and moderately variable SAT REM-200.
-two lower zones of reduced SAT REM, SUSCand SAT REM-200.

For WA-22:
-all magnetic property values gradually increase versus depth.
-a zone of locally reduced SUSC near the top of the core is associated with a local increase in the SAT REM-200.

The chemical and petrological studies indicate that only 6 of the 64 specimens in this collection can be allocated to the zone of altered tailings. Clearly there are insufficient samples to use susceptibility to "map" flow patterns in the unsaturated zone as previously reported for the ORF lysimeter samples. It must be noted, however, that there is a correspondance between the enhanced sulfur and enhanced susceptibility in the altered zone of WA20, and the depleted sulfur, and depleted susceptibility in the altered zones of cores WA2 and WA22.

The chemical analyses showed that copper provides a good estimate of the depth of the alteration front. Does SUSC detect the same boundary ? This hypothesis can be tested by comparing the individually normalised variations of susceptibility and copper content versus depth. (Individual normalisation means that for each parameter the absolute values are recalculated in terms of standard deviations from the individual core mean.) As is clearly shown in figure 10 susceptibility deviations do indeed distinguish the same boundary as copper deviations.

For the majority of samples in this collection the observed magnetic property variations are clearly related to the deposition of the tailings. As noted earlier the magnetic property data provide access to two parameters relating to the deposition of the tailings; magnetic mineral concentration, and magnetic mineral grain size. In the next section we compare the magnetic property and geological concentration and grain size estimates.

Petrological studies indicate the most common minerals present in the tailings are pyrite and pyrrhotite. The accessory minerals are sphalerite, chalcopyrite, and galena. If we assume that all the sulfur present in the tailings was present as sulfide minerals it is possible using the measured values for S,

Fe, Cu, Zn, and Pb to calculate a theoretical sulfide content for each sample of tailings. For the iron in this calculation we assumed a mineral ratio of 60 wt% pyrite and 14 wt% pyrrhotite. The results of this calculation as displayed in figure 11 reveal:

-Cores WA20 and WA22 have on average a higher calculated sulfide content than core WA2.

-Cores WA2 and WA22 both exhibit a shallow near surface zone of calculated sulfide content depletion. In contrast WA20 shows enhanced calculated sulfide content for the same zone.

-The clay rich tailings in both WA2 and WA20 are characterised by extremely low calculated sulfide levels.

The magnetic mineral content variations are calculated from the SAT REM - SUSC distance as outlined above. When plotted versus depth (figure 12) the magnetic mineral content parameter has many similarities to the calculated sulfide content parameter. A correlation between these concentration parameters (figure 13) yields a percentage fit of 83%. From this correlation equation it is possible to recalculate the sulfide concentration parameter in terms of the magnetic concentration parameter.

Comparing the recalculated sulfide concentration parameter and the observed magnetics concentration parameter (figure 14) it is possible to recognise the following features:

WA2

-while there is a broad similarity between the two concentration parameters the magnetic parameter did not detect the detailed sifide content variations between 10 and 17.5 feet.

-in the upper part of the core the magnetic concentration parameter is significantly displaced above the sulfide parameter.

WA20

-with only two minor exceptions there is a very close agreement between the two concentration parameters.

WA22

-this core shows a simple threefold subdivision. Above 6 feet and below 25 feet there appears to be a simple 1:1 relationship between the two concentration parameters. Between 6 feet and 25 feet the magnetic mineral content parameter is systematically below the sulfide parameter.

There appears to be three distinct types of relationship between the sulfide, and magnetic mineral concentration parameters.

1) A simple 1:1 ratio. This is most prominent in WA20, but is also present in the upper and lower sections of WA22.

2) Magnetic concentration is systematically lower than the sulfide concentration. These tailings have more sulfide mineral per unit of magnetic mineral. This type is prominent in the central section of WA22, and in a shorter section of WA20.

3) Magnetic concentration is systematically higher than calculated sulfide content. In these tailings some of the sulfide is replaced by silicates. This type of material is only found in

the silt rich tailings of core WA2, and in the clay rich zones of core WA20.

The magnetic mineral grain size parameter was derived from the SAT REM - SUSC ratio as outlined above. When plotted versus depth (figure 15) the magnetic grain size parameter is also very similar in general form to the observed median grain size variation. A correlation (figure 16) between the two grain size parameters gives a percentage fit of 88%.

The corrected magnetics grain size parameter and the observed median grain size parameter (figure 17) are identical for the majority of samples. For the two clay zones in core WA20, especially the upper one, the magnetics grain size appears to be coarser than the observed grain size.

MAGNETIC PROPERTIES SUMMARY

Magnetic susceptibility and the ratios between saturation remanence and magnetic susceptibility as documented in these samples from the Waite-Amulet tailings reveal:

a) Primary depositional variations of the tailings.

Decreasing grain size in the tailings is directly reflected by decreasing oxide grain size. Oxide mineral content shows systematic correlations with sulfide mineral content. It is this latter feature that permits the differentiation between the sand and silt rich tailings. These two groupings correspond respectively to the category one (uniform high SUSC, high SAT REM) and category two (moderate variable SUSC and SAT REM) magneto-lithologies of our previous report. Apart from differences of magnitude there are no diagnostic chemical differences between these two groups. The category three grouping (low SUSC, low SAT REM) corresponds to clay rich tailings. This group is also characterised by significantly enhanced silicate mineral content relative to the category one and two type tailings.

b) Secondary alteration effects in tailings.

In tailings of uniform grain size like WA20 the developed alteration is clearly identified by all magnetic parameters. Where alteration is complicated by the presence of lithology changes the observed susceptibility changes may represent a combination of the two effects. For example in WA22 the immediate surface sample shows susceptibility enrichment associated with reduced Cu, Zn, and Pb, a sure indication that it is detecting alteration. Yet the next sample with reduced susceptibility records the effect of a local silt rich horizon. Likewise, the top two samples from WA2 appear to show the effects of alteration (reduced Cu, and Zn) but this same zone is also characterised by reduced susceptibility. With the limited number of samples from this alteration zone it is not possible to establish whether susceptibility is "mapping" flow in the unsaturated tailings.

RECOMMENDATIONS

At the commencement of this study our intention was to compare results from a natural tailings environment with the results we had previously obtained from a study of the artificially weathered tailings of the ORF lysimeter experiment. Magnetic susceptibility results from the ORF lysimeter experiment outlined what was felt to be a drainage pattern of fluids migrating through the tailings. In the ORF experiment all the lysimeter bed was exposed to fluid migration; the lysimeter bed corresponded to the zone above the water table in a natural tailings setting. There is no standing water in this portion of the tailings, hence it is not possible to use fluid chemistry, or fluid dynamics techniques to document the preferred fluid pathways through this portion of the tailings. On the basis of our ORF results it was hoped that magnetic susceptibility could offer a key to this problem.

Unfortunately, of the 64 samples examined in this study only 6 came from the the oxidised portion of the tailings above the water table. However even from these few results it is apparent that oxide enhancement, and depletion related to alteration is present in the Waite - Amulet tailings. Further a recent report by Jambor (1987) confirms that there is detailed fine structure within the alteration zone of the tailings. What is the significance of this fine structure ? How does the fine structure in one core compare to the structure in another nearby core ? Why does the base of the alteration zone as defined by Jambor (1987) vary from being abrupt to quite diffuse ? What is the preferred fluid pathways through this upper altered portion of the tailings, is it uniform, or focussed ? Are there any sedimentological inhibitors to preferred fluid motion ? At present there are no answers to all of these questions.

We recommend that a suite of samples be examined from a collection of 36 cores to be obtained from a 6m by 6m grid. Each core will sample only the top 1m of the tailings, that is the portion covering the alteration zone, and the top of the unaltered tailings. Each core will then be subdivided into 20cm segments, and then analysed for chemical, sedimentological, and magnetic property variations. From this it is hoped that it should be possible:-

a) to outline the factors controlling alteration in the tailings above the water table.
b) to obtain information on the preferred flow directions in the unsaturated tailings.
c) to document controls on the depth extent of the alteration surface.
d) to quantify the correlations of the elemental concentrations with depth.
e) to quantify the correlations between the magnetic properties of the core and the chemical and physical properties of the core.

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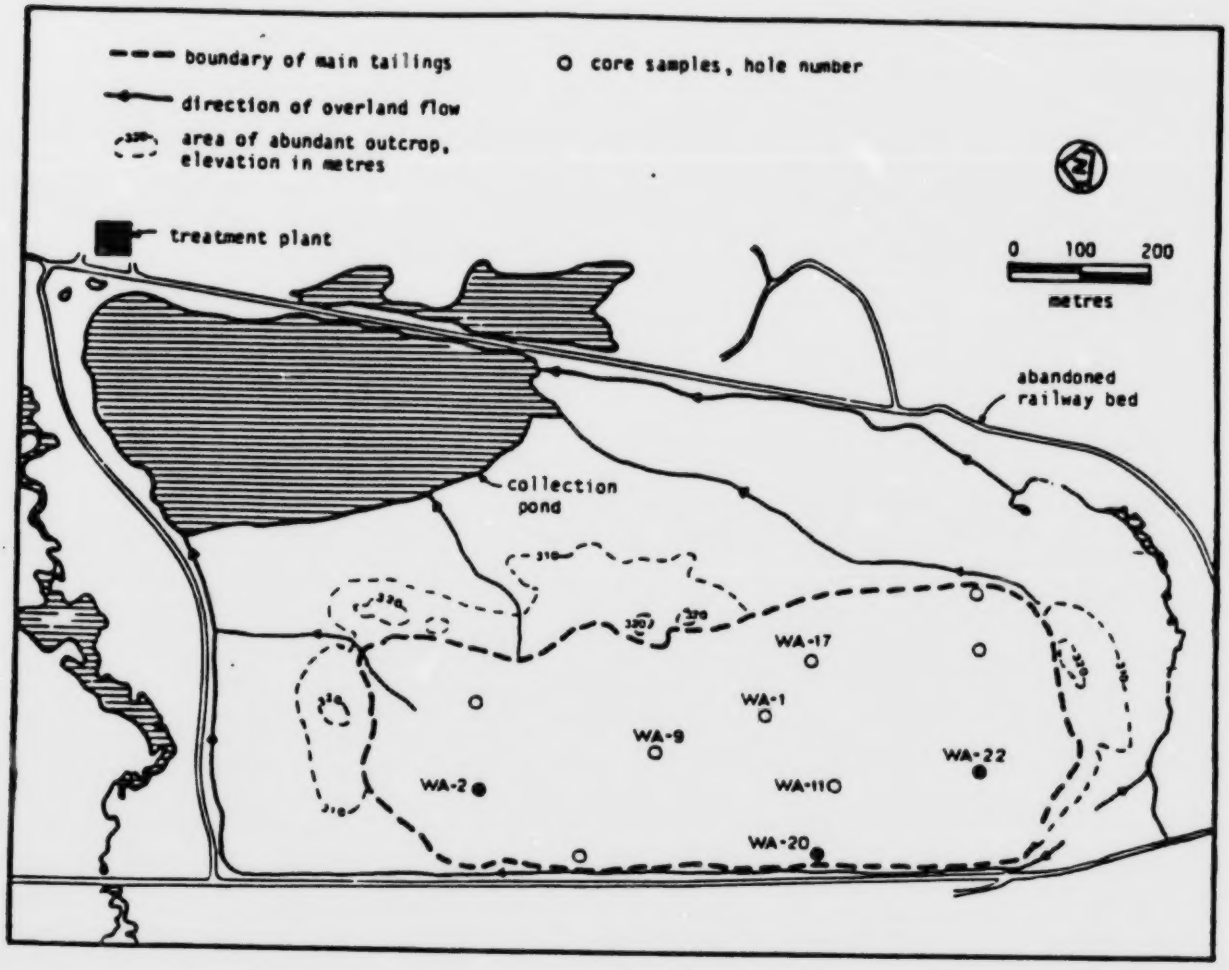


Figure 1
Location of Cores WA2, WA20, and WA22 in the Waite -Amulet Tailings basin.

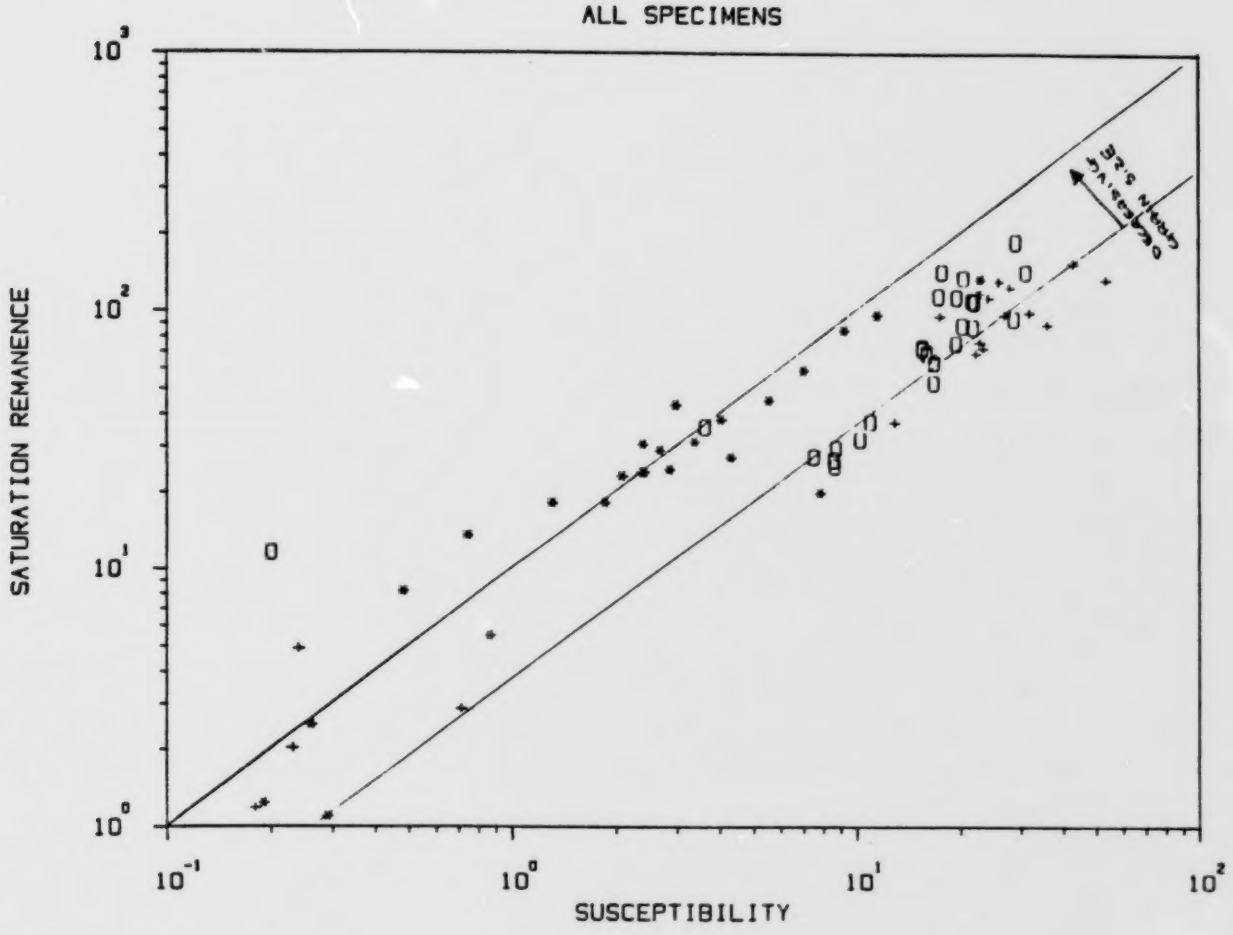


FIGURE 2
Plot of susceptibility versus saturation remanence. Cores are WA2 (*), WA20 (+), and WA22 (O).

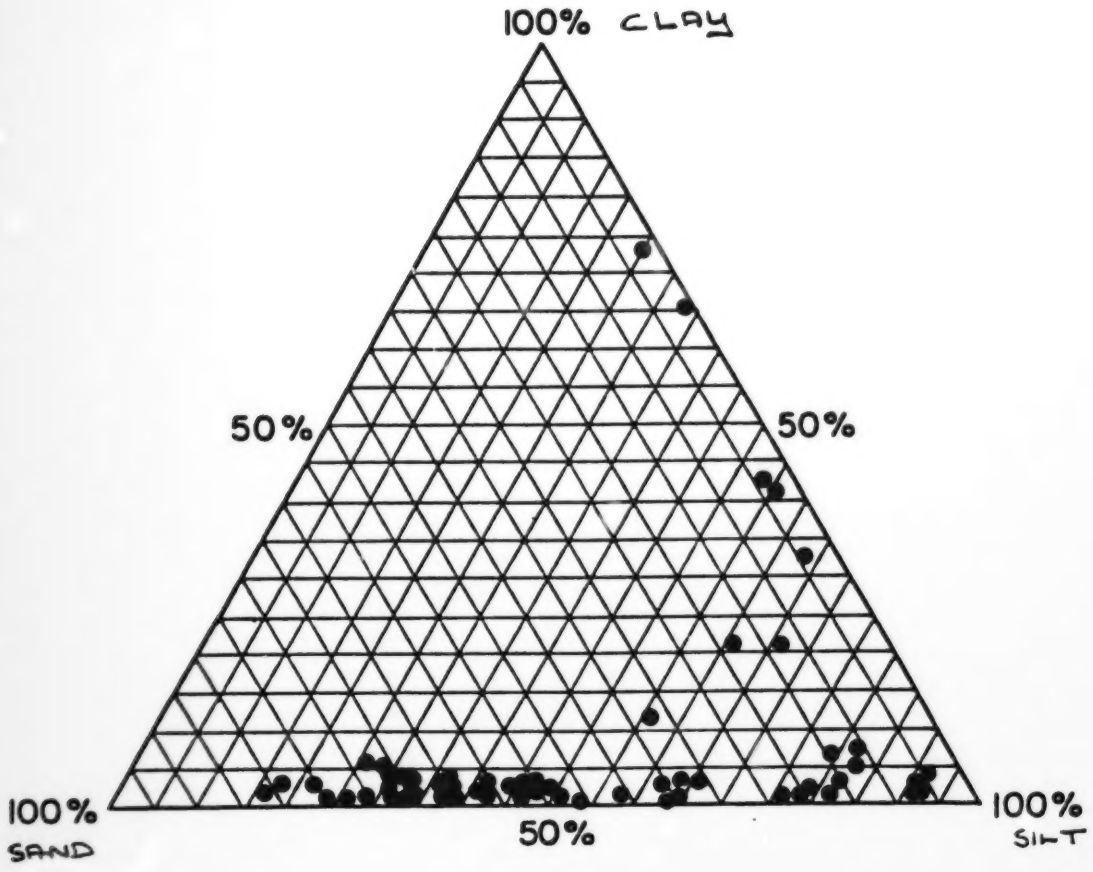


FIGURE 3
Granulometric composition of tailings samples.

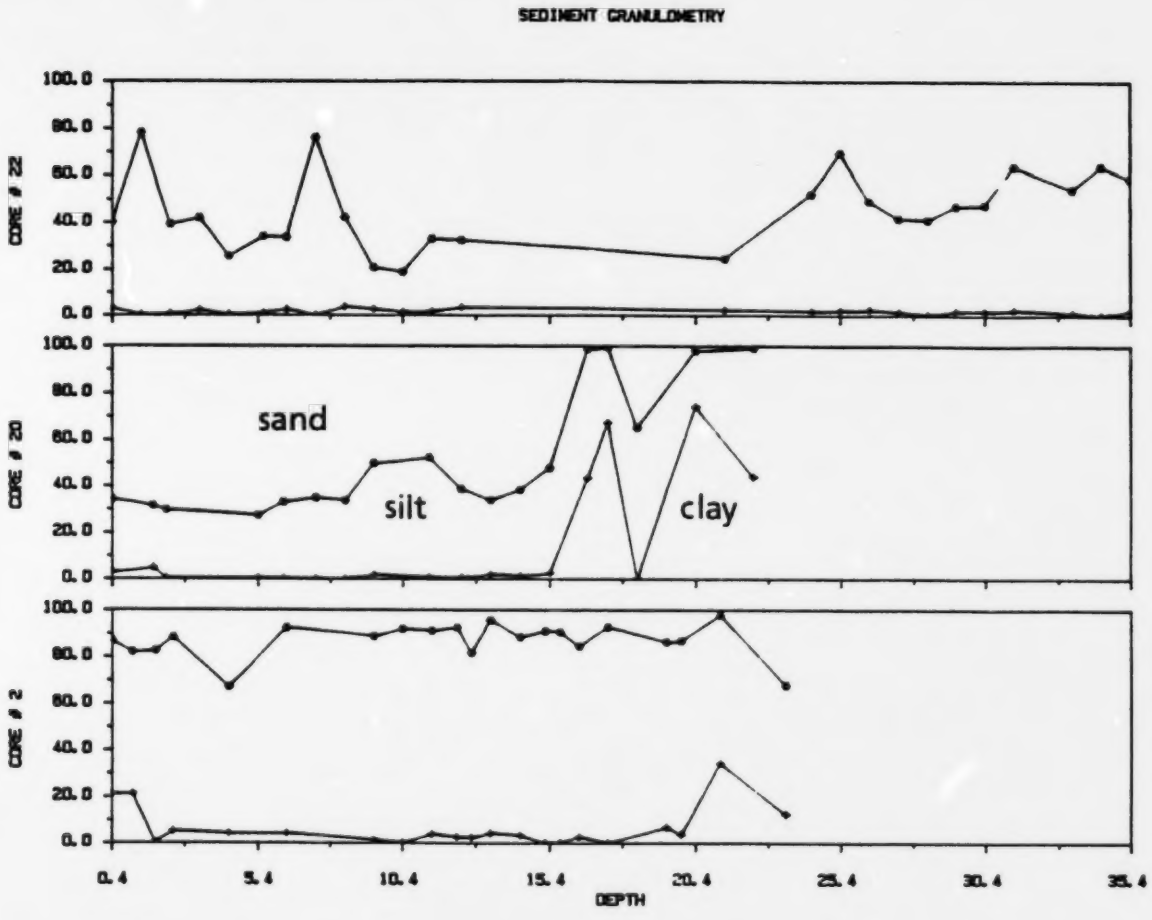


FIGURE 4
Plot of the vaiation of sand, silt and clay content versus depth.

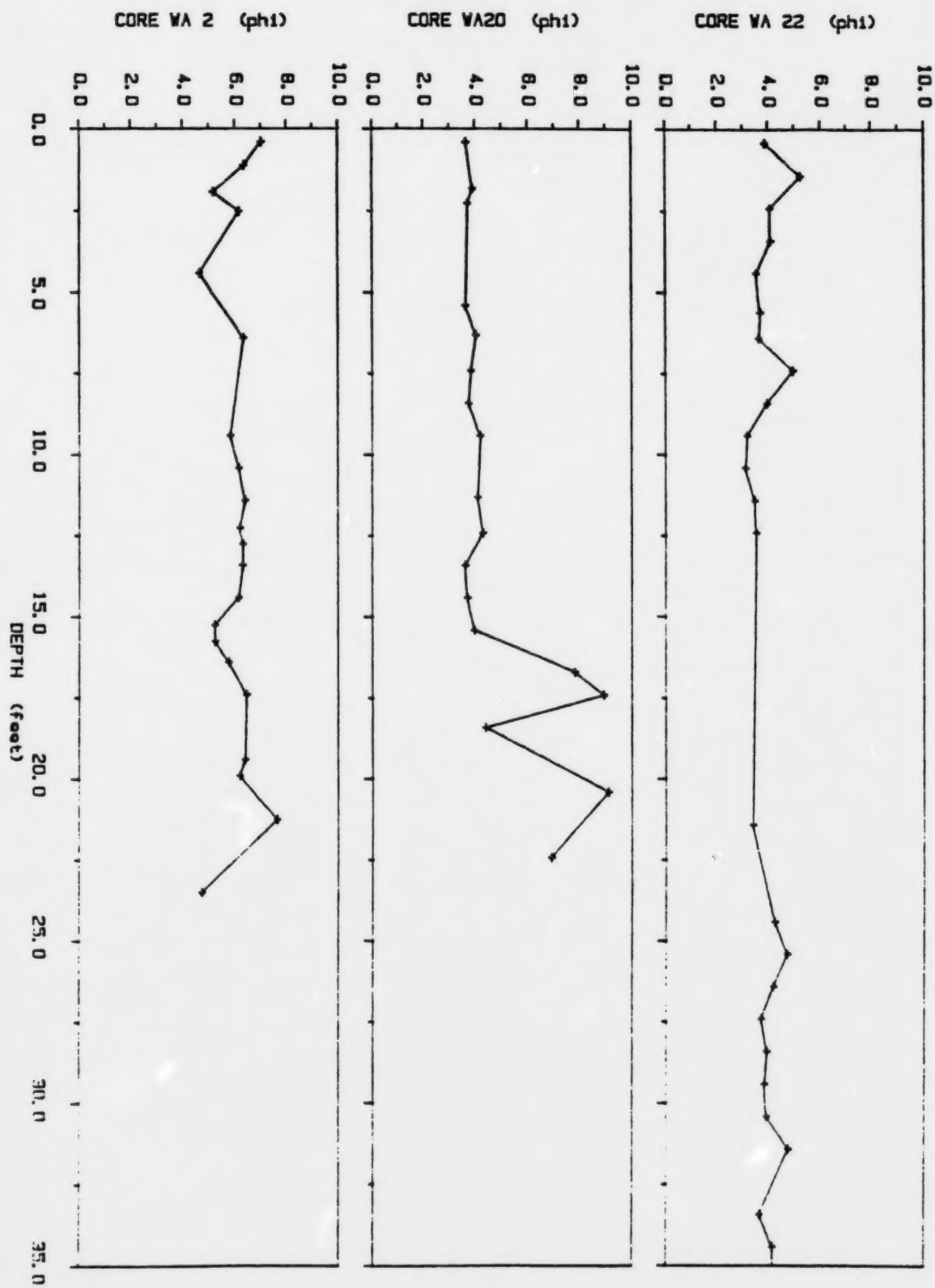


FIGURE 5
Plot of median grain size versus depth.

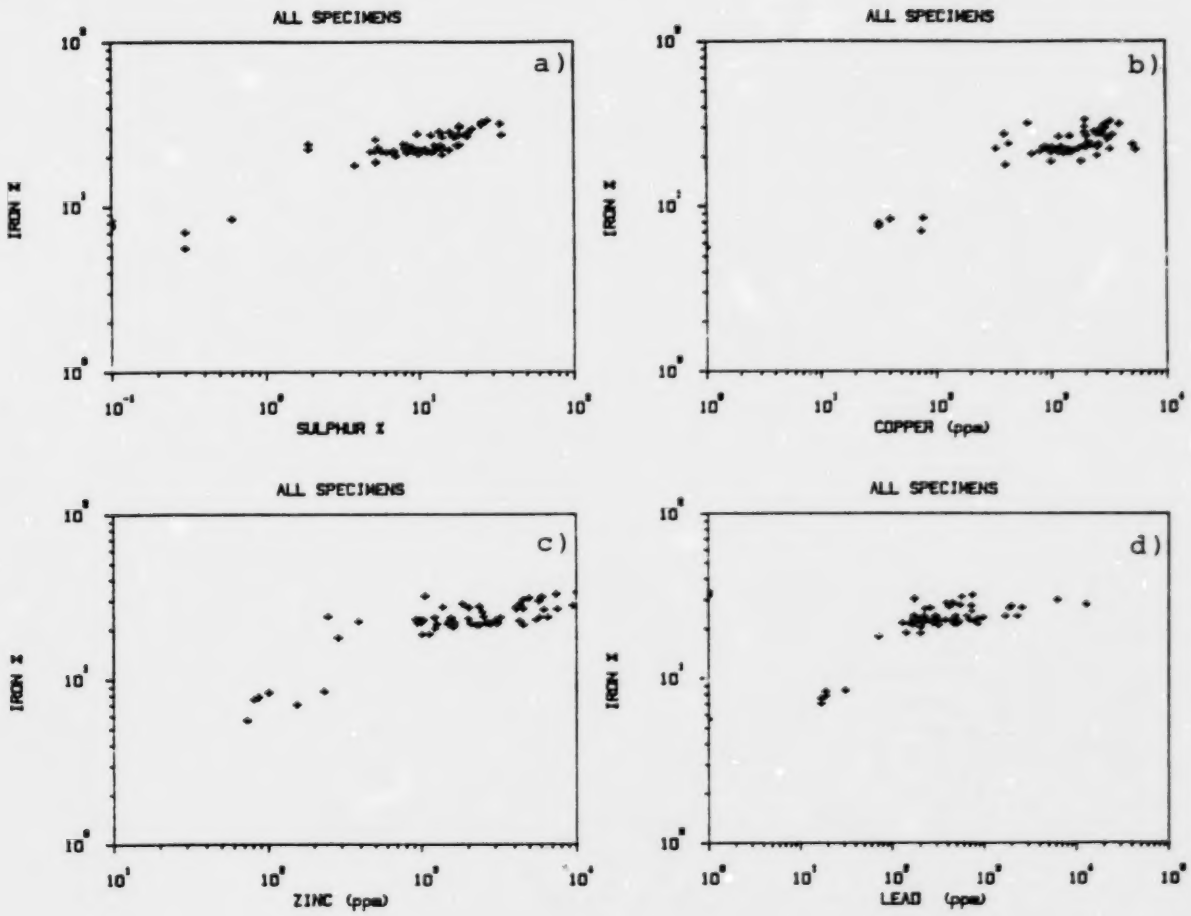


FIGURE 6
Plot of iron concentration (%) versus: a) sulphur (%), b) copper (ppm), c) zinc (ppm), and d) lead (ppm).

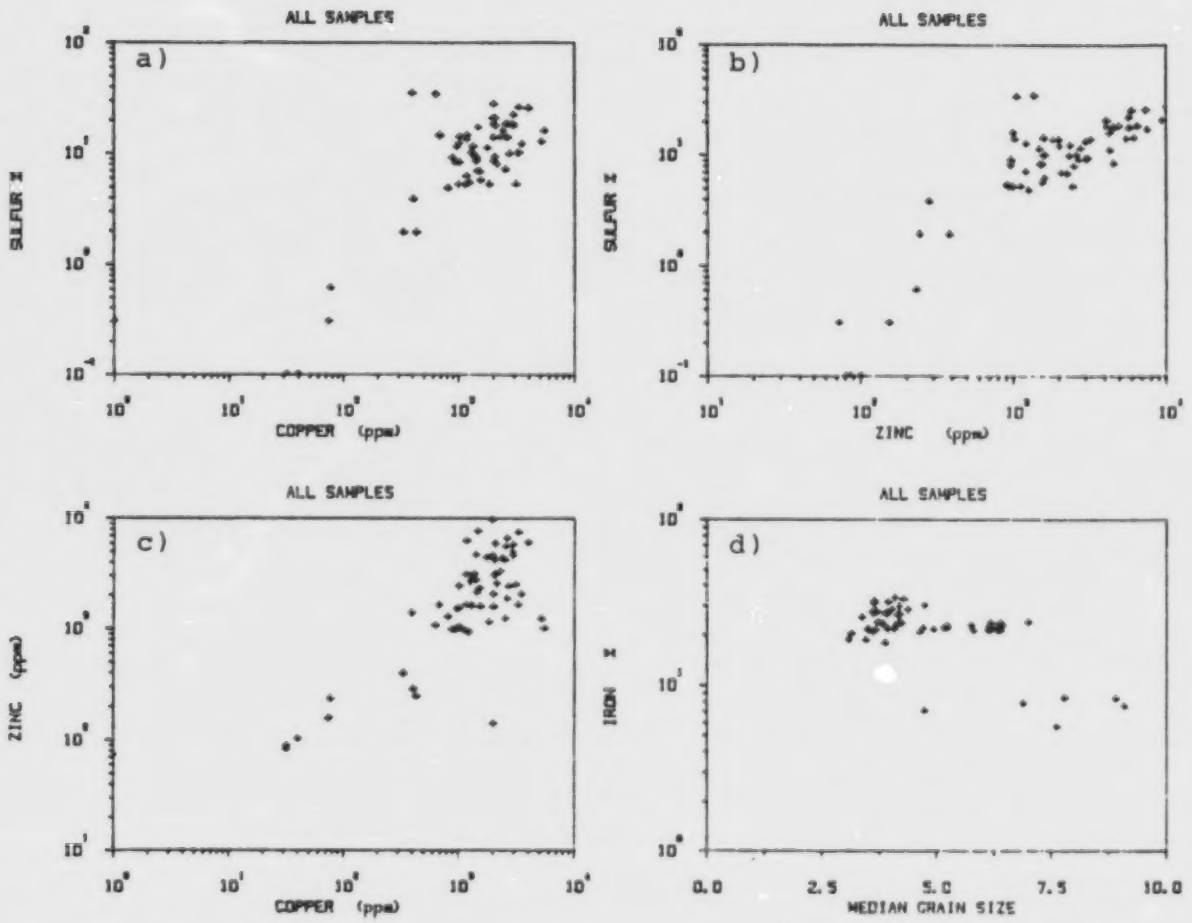


FIGURE 7
a) plot of Sulphur (%) vs. Copper (ppm).
b) plot of Sulphur (%) vs. Zinc (ppm).
c) plot of Zinc (ppm) vs. Copper (ppm).
d) plot of Iron (%) vs. Median grain size.

FIGURE 8(a)
Plot of chemical variations in tailings versus depth for core WA 2.

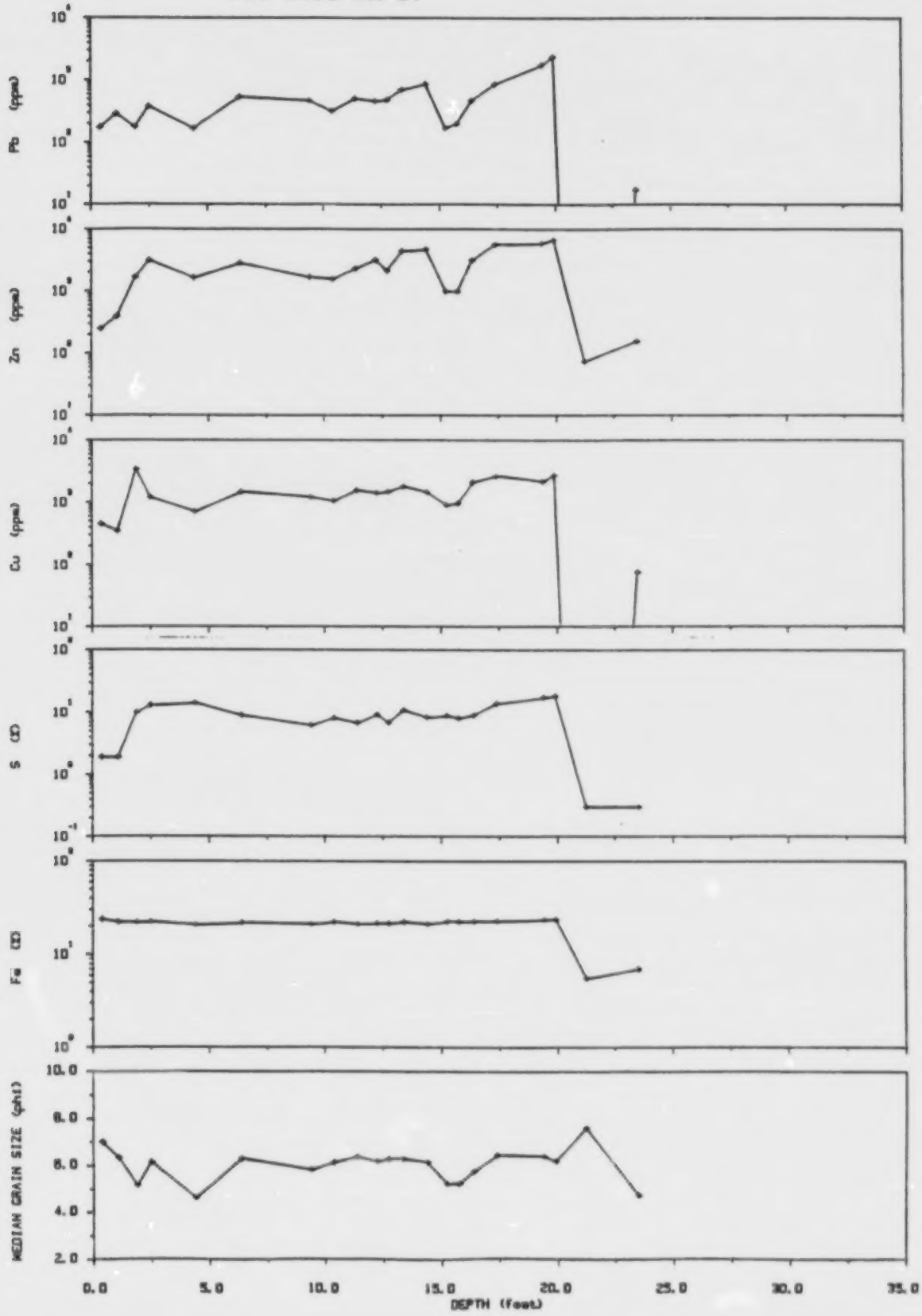


FIGURE 8(b)
Plot of chemical variations in tailings versus depth for core WA 20.

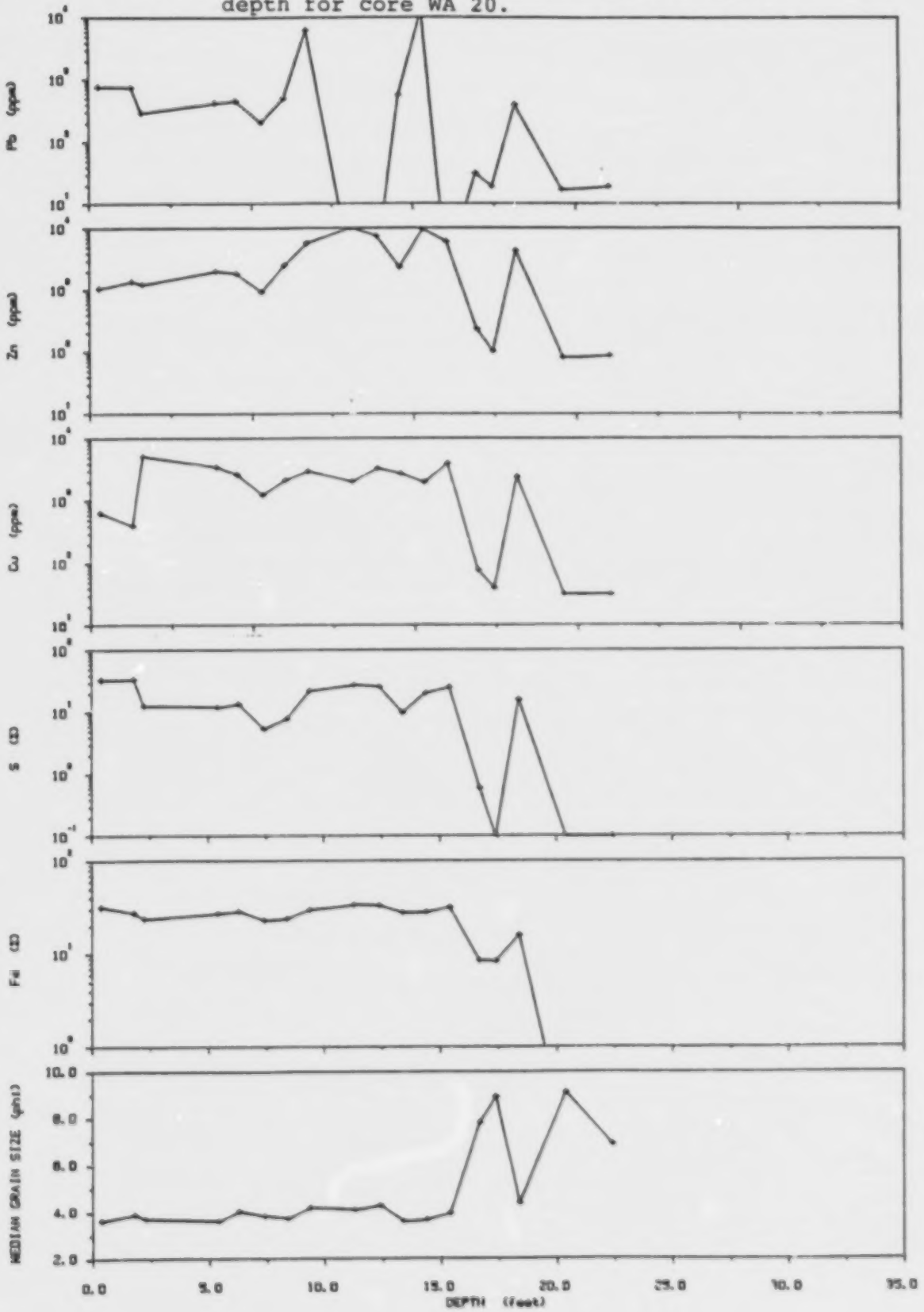


FIGURE 8(c)
Plot of chemical variations in tailings versus depth for core WA 22.

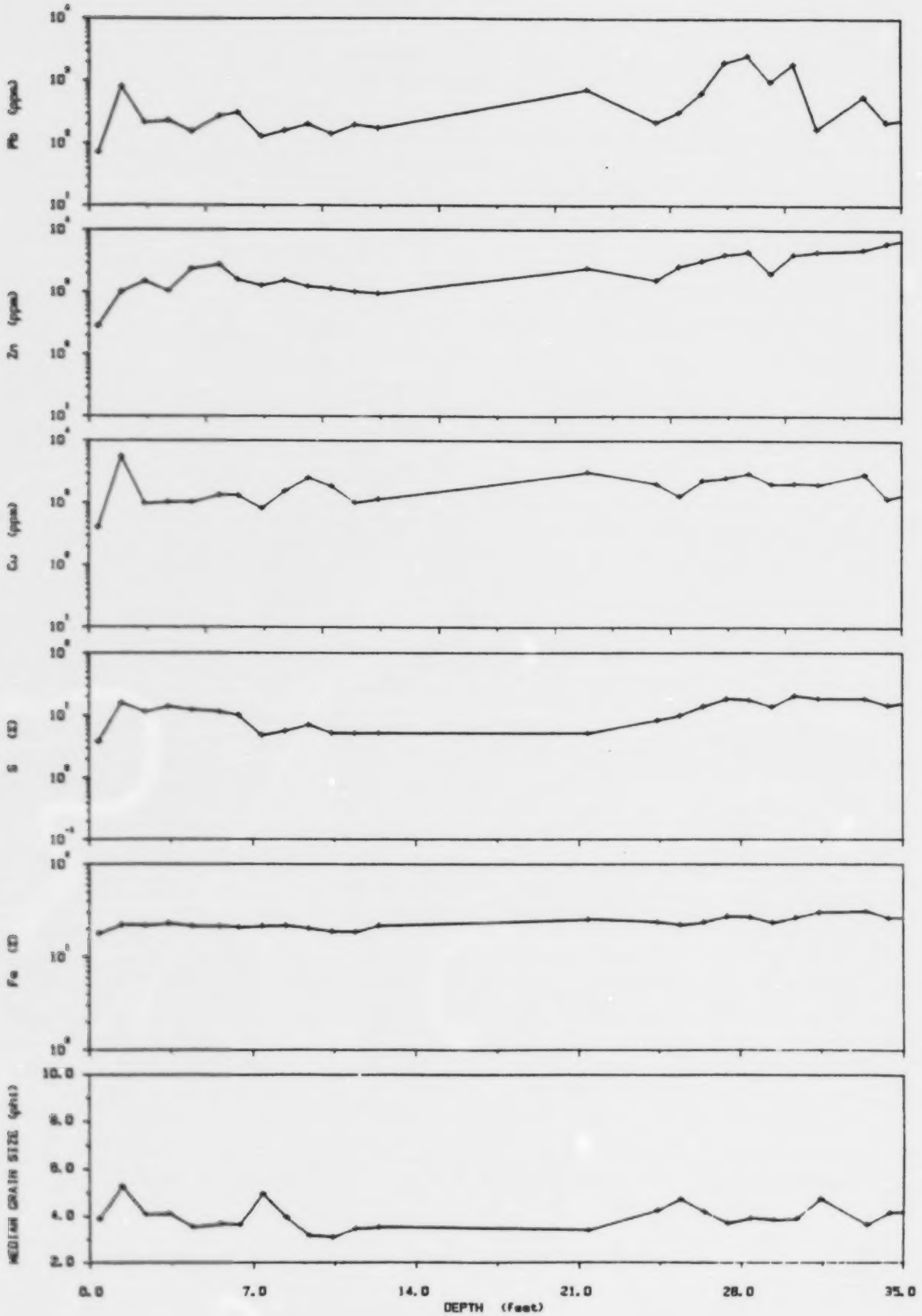


FIGURE 9 (a)
Plot of magnetic property variations versus depth
for core WA 2.

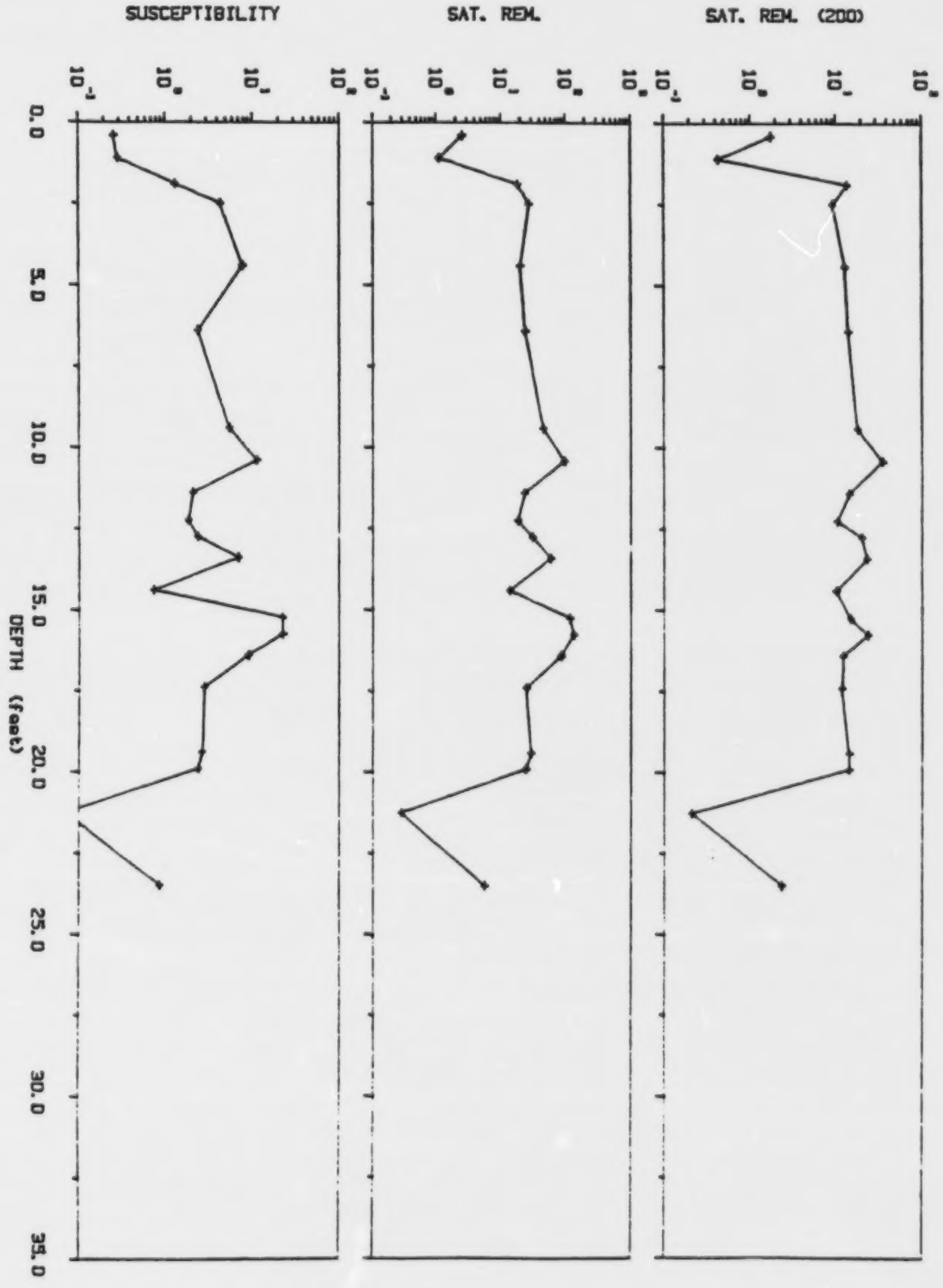


FIGURE 9(b).
Plot of magnetic property variations versus depth for core WA 20.

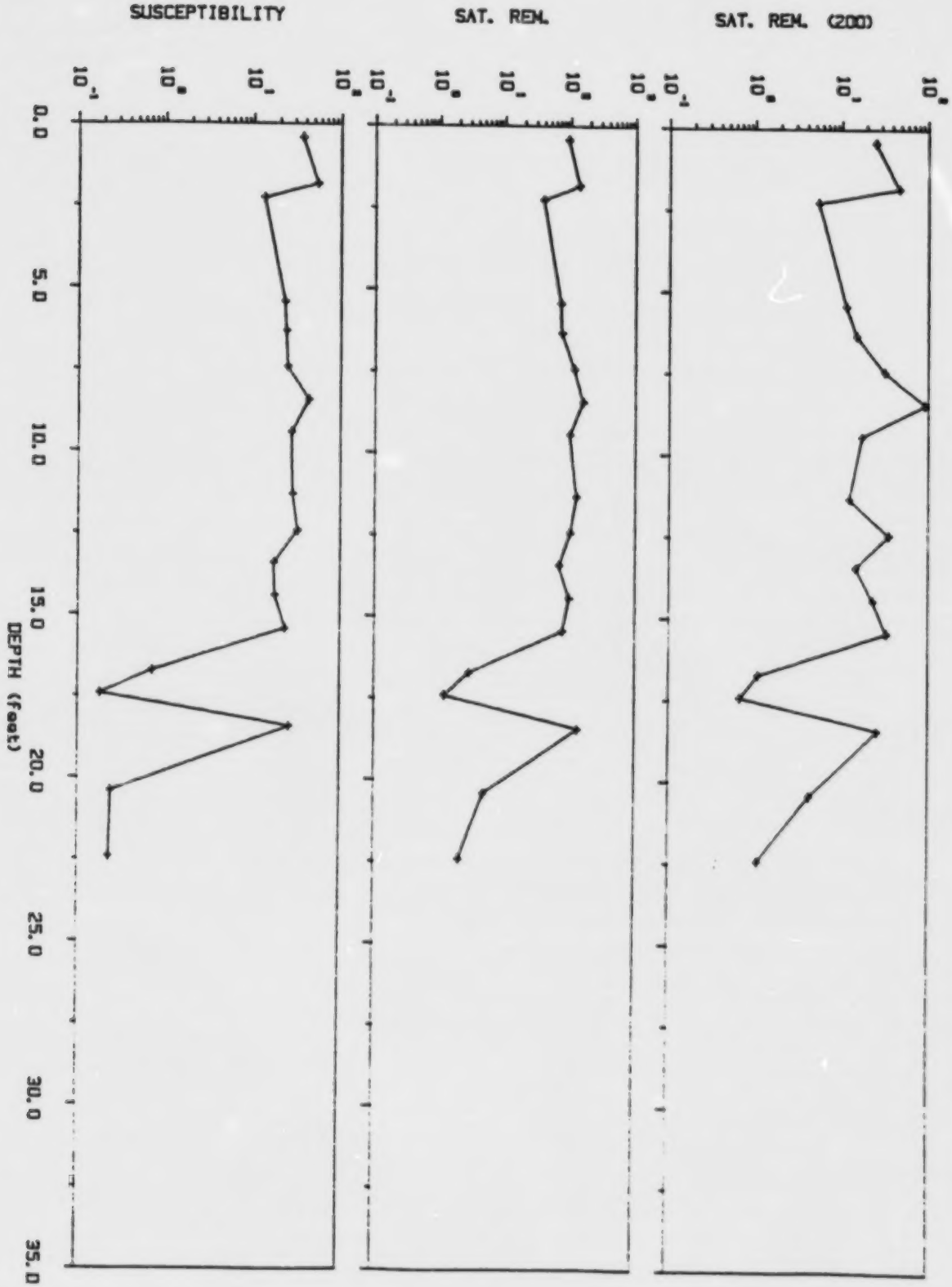


FIGURE 9(c).
Plot of magnetic property variations versus depth for core WA 22.

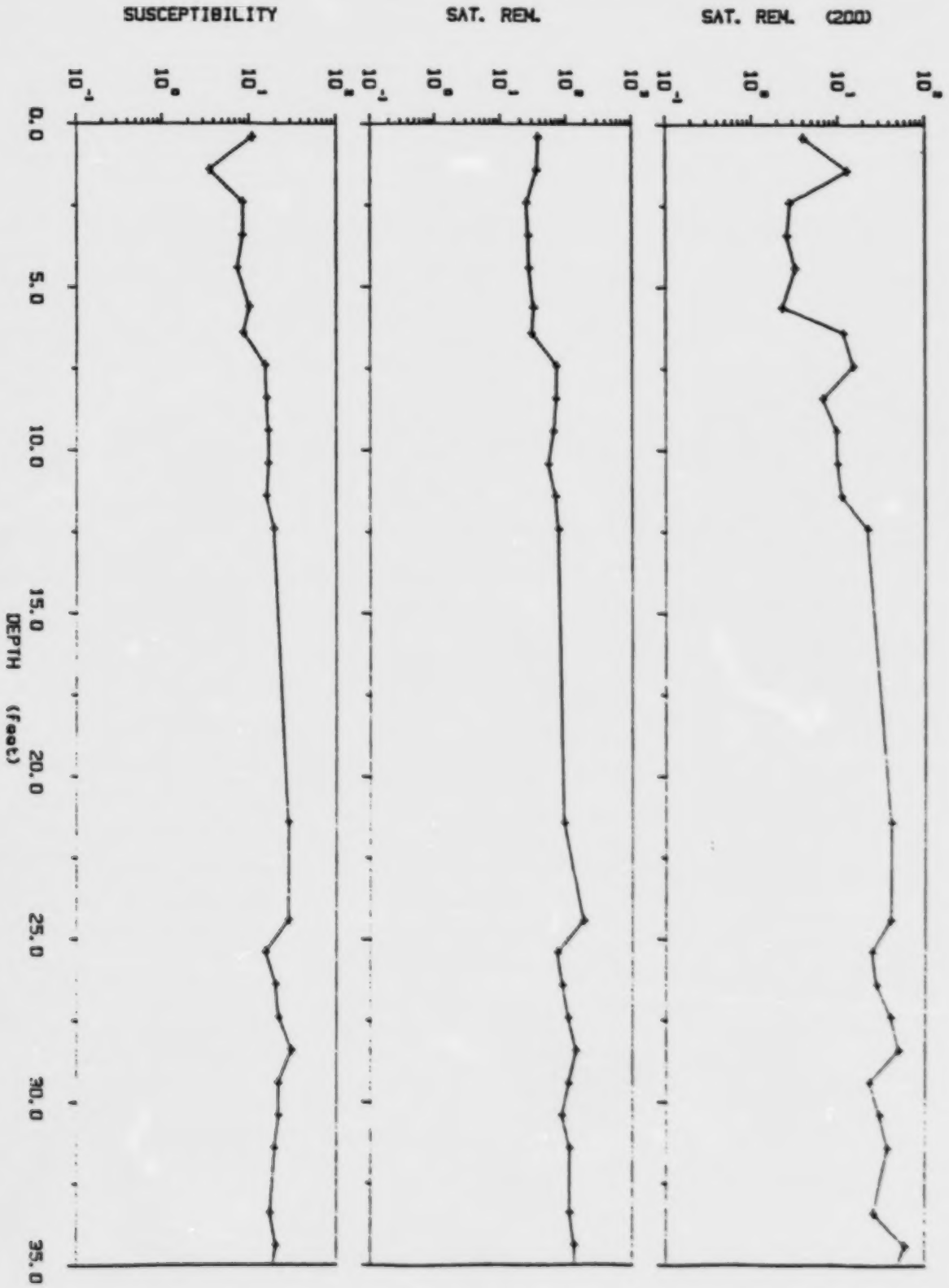


FIGURE 10
Comparison of individually noramlised susceptibility and copper variations for cores WA2, WA20, and WA22.

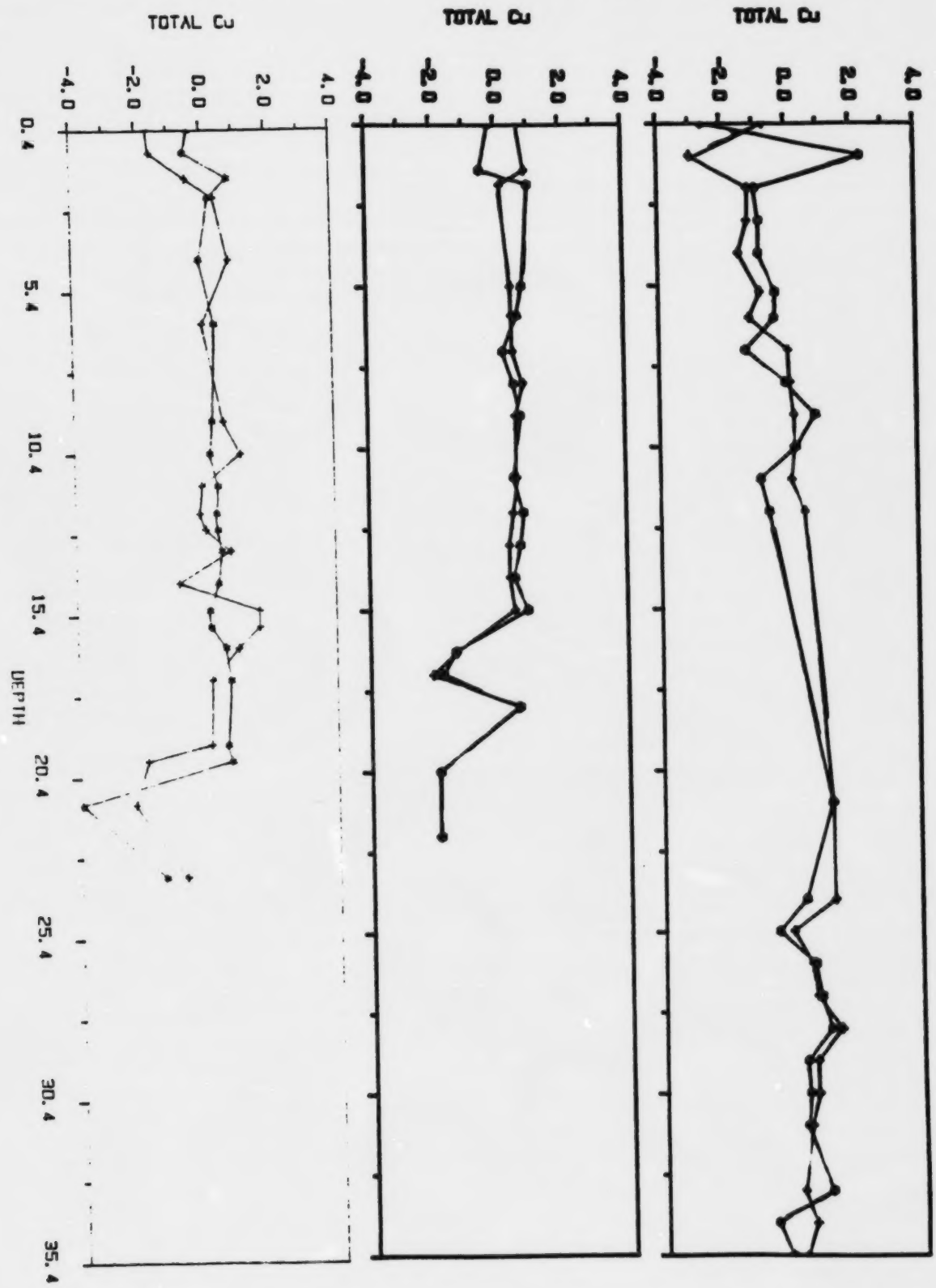


FIGURE 11
Plot of calculated sulfide content versus depth.

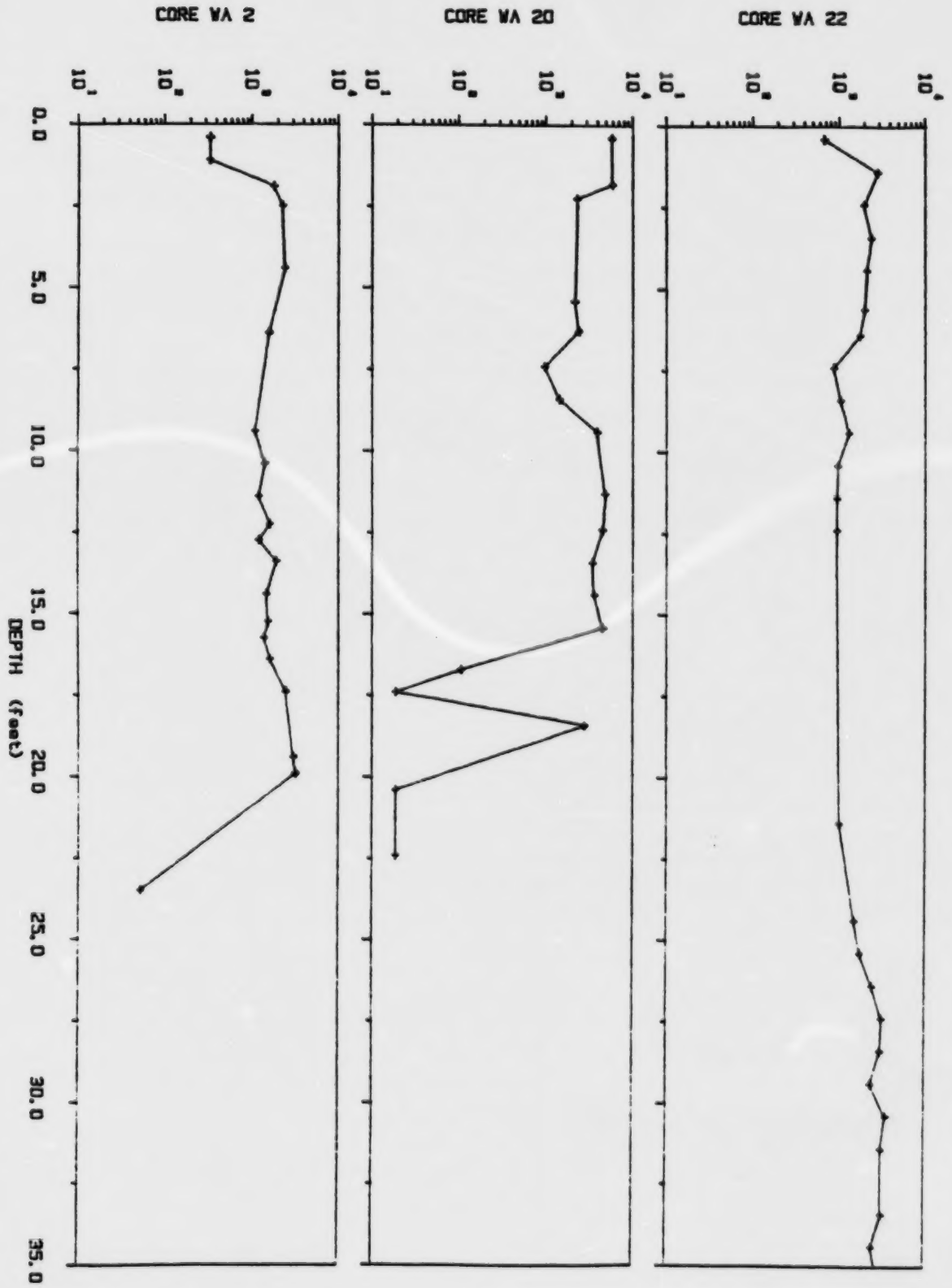
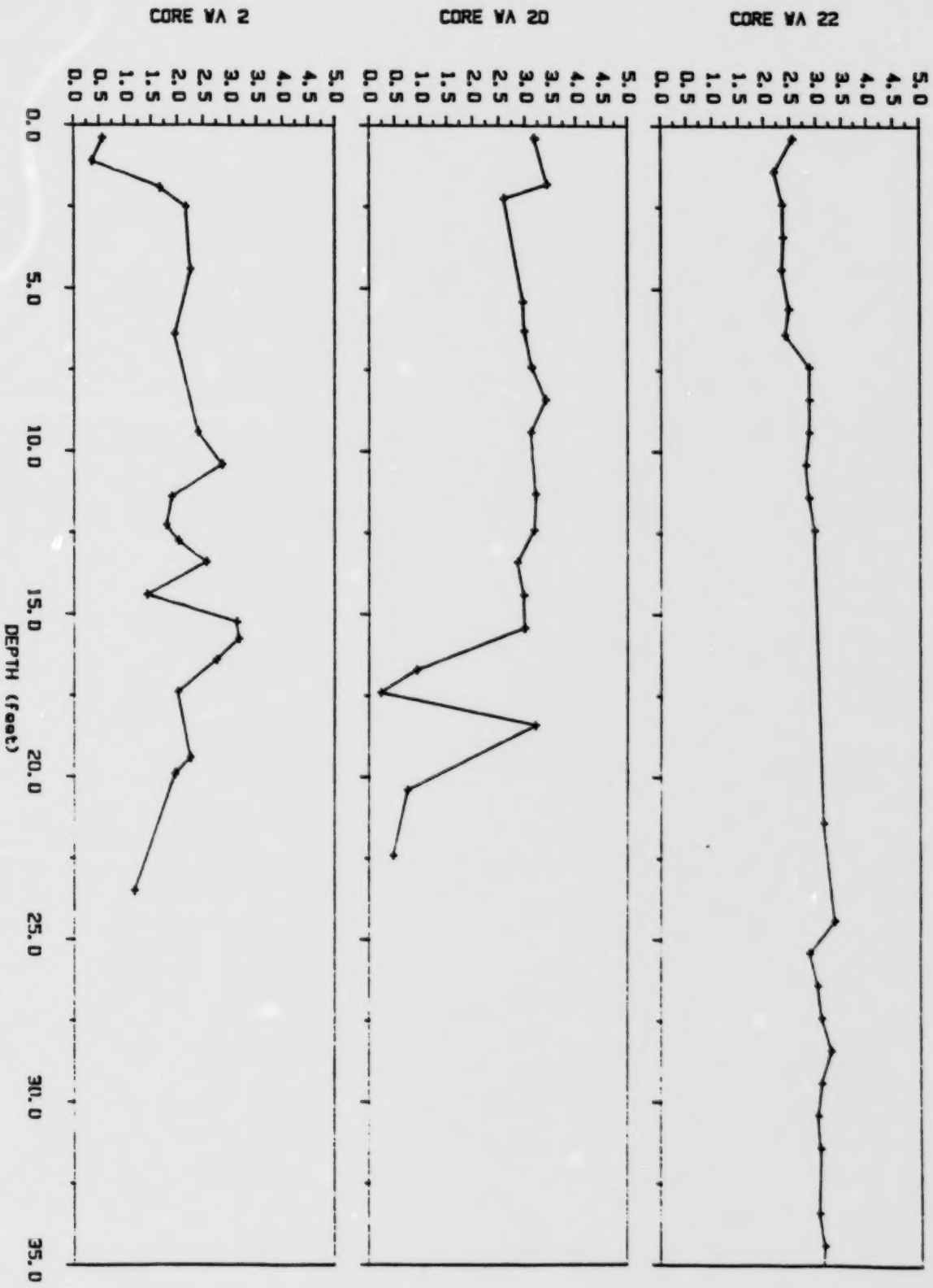


FIGURE 12
Plot of magnetic mineral content parameter versus depth.



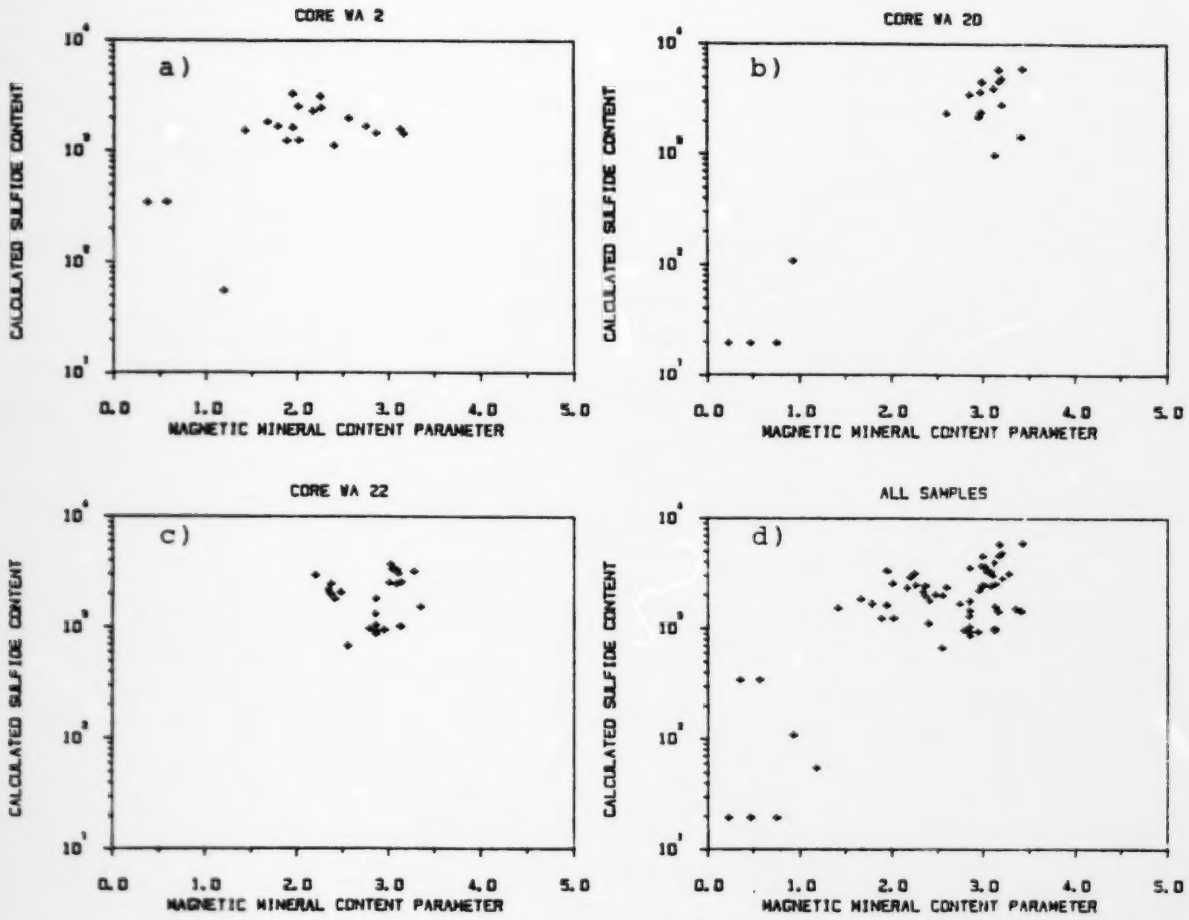


Figure 13
Correlation plots of calculated sulfide content versus magnetic mineral content for:
a) core WA 2
b) core WA 20
c) core WA 22
d) all samples.

FIGURE 14
Comparison of magnetic mineral content (O) and recalculated sulfide mineral content (*) versus depth.

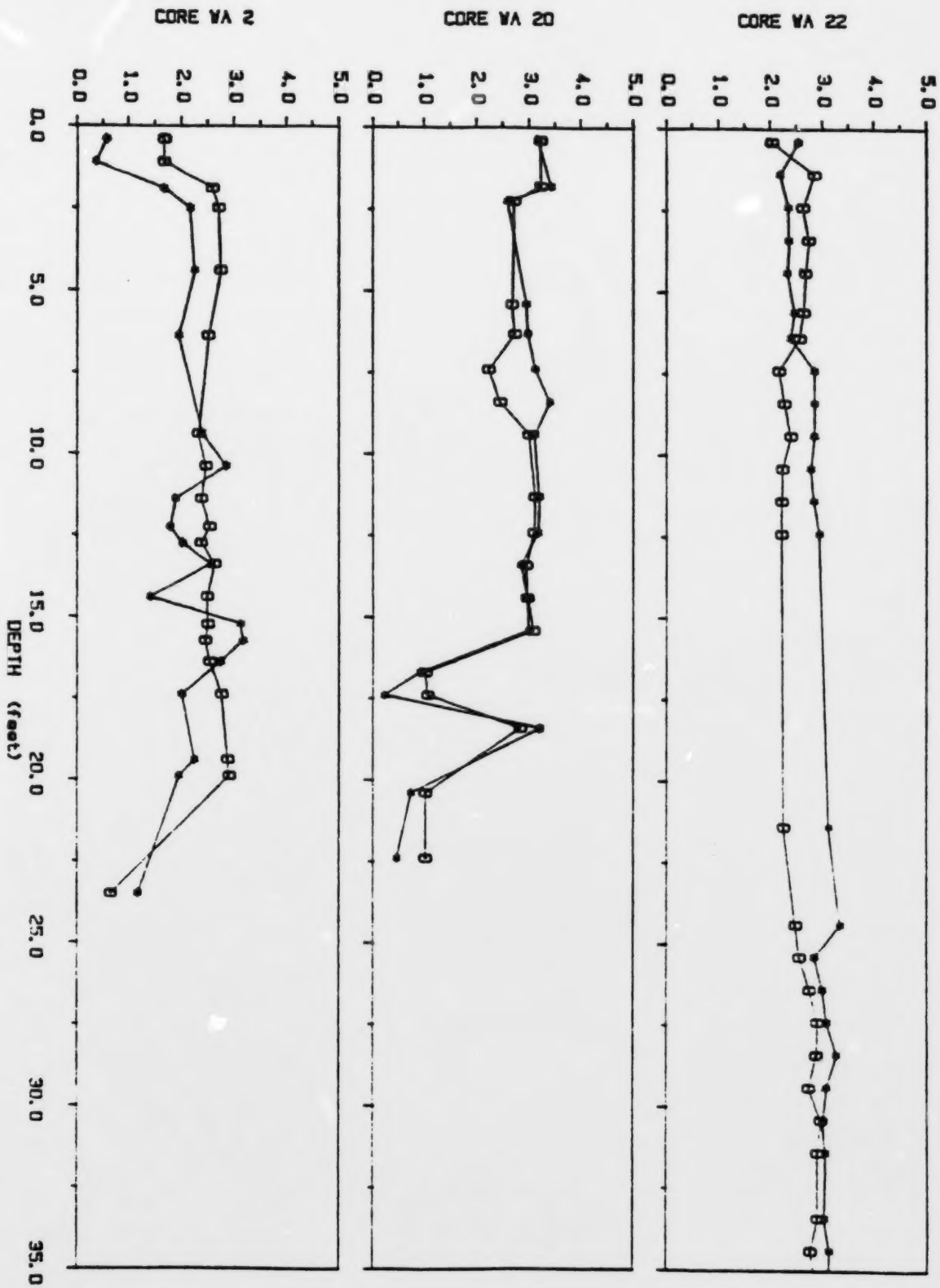
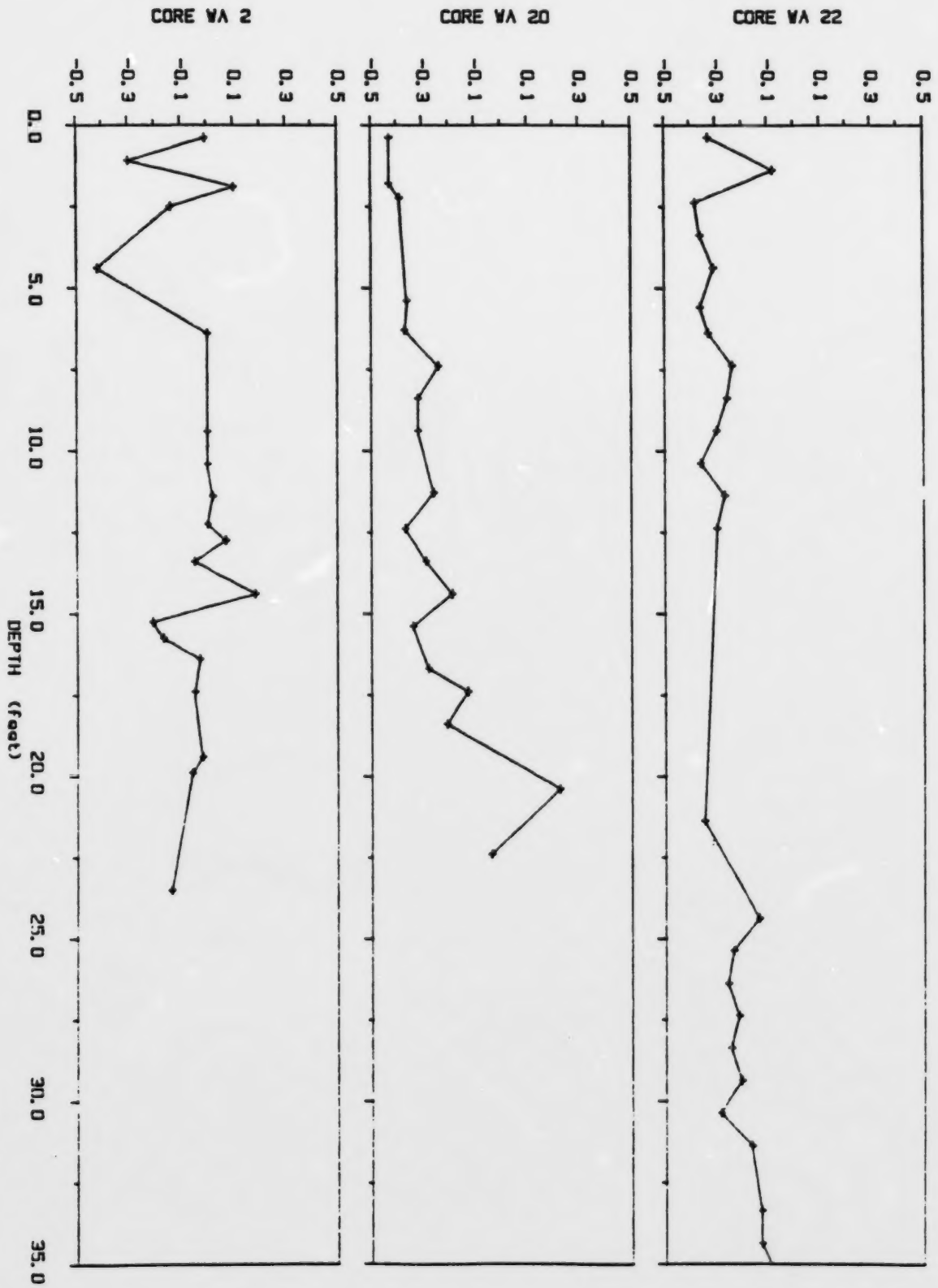


FIGURE 15
Plot of calculated magnetic grain size variation versus depth.



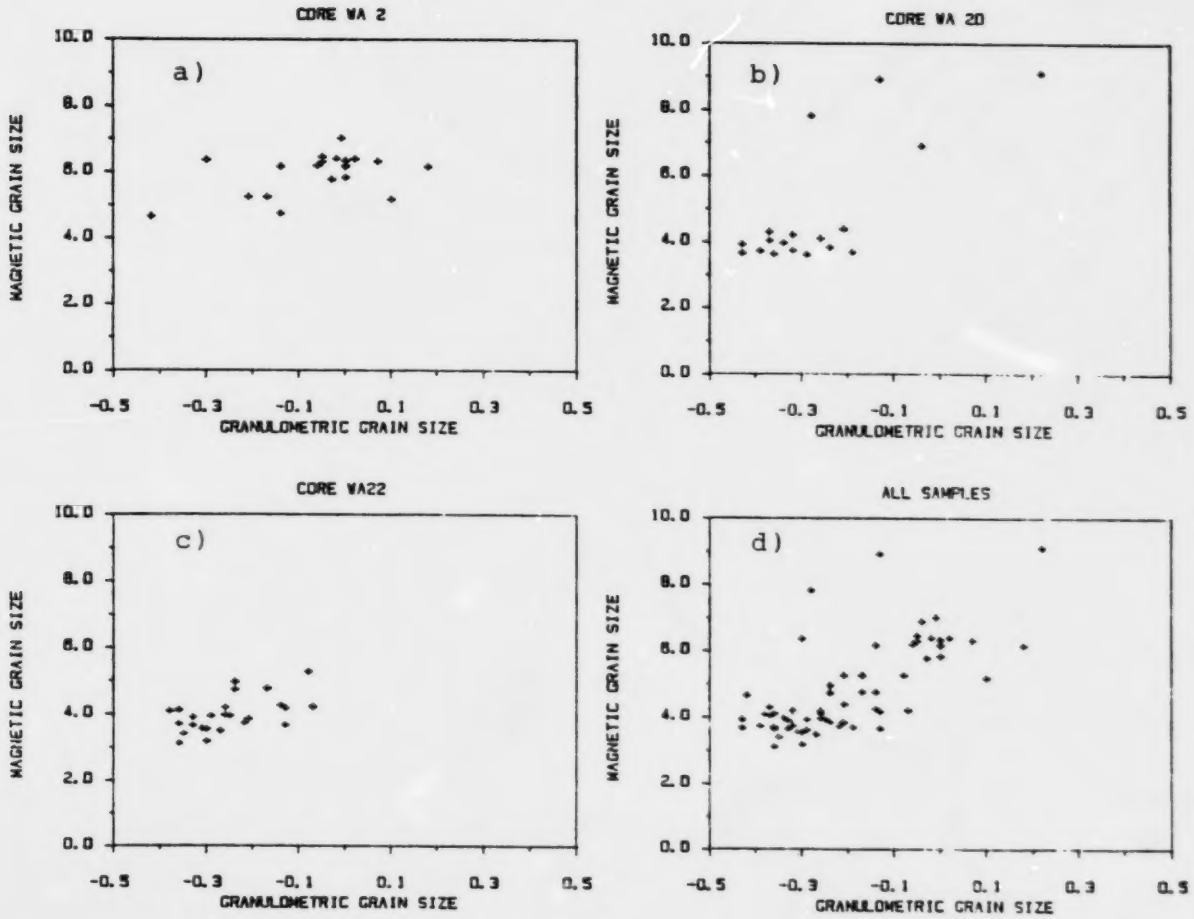


FIGURE 16
Correlation plots of magnetic mineral grain size versus granulometric grain size for
a) core WA 2
b) core WA 20
c) core WA 22
d) all samples.

FIGURE 17
Comparison of recalculated magnetic mineral grain size(O) versus observed granulometric grain size.

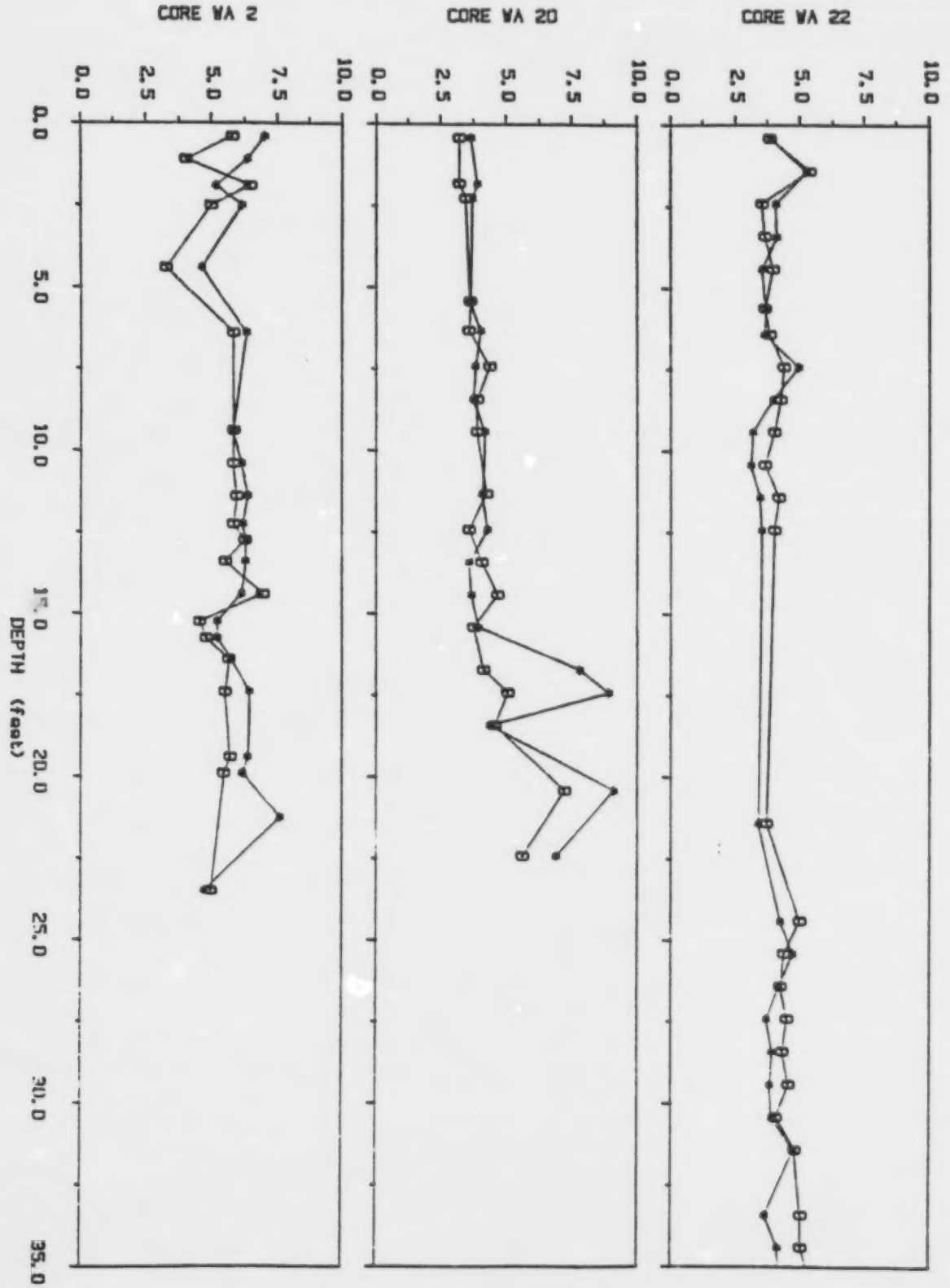


TABLE 1

CORE # WA2

	DEPTH	SPEC #	SUSC. (cgs.)	SAT. REM. (emu.)	SAT. REM.(200) (emu.)
1	0.4	64	0.26	2.50	1.74
2	1.1	63	0.29	1.10	0.42
3	1.9	62	1.30	18.20	13.50
4	2.5	61	4.27	27.20	9.16
5	4.4	60	7.80	19.90	12.82
6	6.4	57	2.37	23.80	14.00
7	9.4	54	5.51	45.10	18.10
8	10.4	56	11.39	96.50	35.50
9	11.4	55	2.07	23.00	14.30
10	12.25	53	1.85	18.20	10.30
11	12.75	52	2.38	30.60	20.30
12	13.4	51	6.96	59.10	23.40
13	14.4	50	0.74	13.60	9.99
14	15.25	75	22.61	117.00	14.70
15	15.75	74	22.88	133.70	24.00
16	16.4	73	9.15	84.60	12.00
17	17.4	72	2.84	24.40	11.60
18	19.4	68	2.66	28.88	14.10
19	19.9	69	2.40	23.80	14.00
20	21.25	67	0.07	0.28	0.21
21	23.5	65	0.86	5.50	2.34

TABLE 2

CORE # WA2

	DEPTH	SPEC #	A	B
1	0.4	64	0.57	-0.01
2	1.1	63	0.36	-0.30
3	1.9	62	1.67	+0.10
4	2.5	61	2.17	-0.14
5	4.4	60	2.26	-0.42
6	6.4	57	1.95	0.00
7	9.4	54	2.40	0.00
8	10.4	56	2.86	0.00
9	11.4	55	1.89	+0.02
10	12.25	53	1.79	0.00
11	12.75	52	2.02	+0.07
12	13.4	51	2.56	-0.05
13	14.4	50	1.42	+0.18
14	15.25	75	3.13	-0.21
15	15.75	74	3.17	-0.17
16	16.4	73	2.75	-0.03
17	17.4	72	2.01	-0.05
18	19.4	68	2.25	-0.02
19	19.9	69	1.95	-0.06
20	21.25	67		
21	23.5	65	1.18	-0.14

A = OXIDE CONTENT PARAMETER
= APPROXIMATELY EQUAL TO DISTANCE OF POINT FROM THE ORIGIN

B = OXIDE GRAIN SIZE PARAMETER
= PERPENDICULAR DISTANCE OF POINT FROM 45 DEGREE LINE PASSING THROUGH ORIGIN

TABLE 3

CORE # WA2

	DEPTH	SPEC #	MED GRAIN	CLAY	SILT	SAND
			I- PHI -I	I------	PERCENT	--------I
1	0.4	64	7.01	21.1	65.7	13.2
2	1.1	63	6.35	21.3	60.7	18.0
3	1.9	62	5.17	0.4	82.2	17.4
4	2.5	61	6.16	5.0	83.4	11.6
5	4.4	60	4.64	4.0	63.1	32.9
6	6.4	57	6.33	4.1	88.3	7.6
7	9.4	54	5.83	1.2	87.5	11.3
8	10.4	56	6.15	0.1	91.9	8.0
9	11.4	55	6.39	3.8	87.3	8.9
10	12.25	53	6.19	2.4	90.2	7.4
11	12.75	52	6.31	2.3	79.3	18.4
12	13.4	51	6.30	4.2	91.7	4.3
13	14.4	50	6.15	3.1	85.3	11.6
14	15.25	75	5.24	0.1	91.0	8.9
15	15.75	74	5.24	0.1	90.5	9.4
16	16.4	73	5.77	2.6	81.9	15.4
17	17.4	72	6.45	0.0	82.8	17.2
18	19.4	68	6.39	6.7	79.6	13.7
19	19.9	69	6.19	3.6	83.2	13.2
20	21.25	67	7.63	34.2	63.7	2.1
21	23.5	65	4.74	12.4	55.4	32.2

TABLE 4

CORE # WA2

	DEPTH	SPEC#	S	Fe	Cu	Pb	Zn	Ni	Co	Cr	V
			I--- % ---I		I---------- ppm. ----------I						
1	0.4	64	1.9	23.9	433	173	244	12	29	28	74
2	1.1	63	1.9	22.3	334	284	387	15	32	56	97
3	1.9	62	10.0	22.1	3285	176	1625	22	104	34	66
4	2.5	61	13.1	22.4	1169	377	3026	47	61	70	84
5	4.4	60	14.2	20.7	685	167	1596	66	62	86	79
6	6.4	57	9.0	21.9	1432	531	2713	47	65	87	104
7	9.4	54	6.2	21.2	1173	467	1613	31	66	93	106
8	10.4	56	8.2	22.4	1021	317	1512	24	68	51	84
9	11.4	55	6.8	21.2	1525	507	2269	20	61	41	95
10	12.25	53	9.3	21.7	1380	460	3092	20	85	25	75
11	12.75	52	6.9	21.7	1452	482	2082	19	59	41	100
12	13.4	51	11.0	22.5	1766	700	4319	20	89	30	66
13	14.4	50	8.4	21.2	1426	860	4583	15	77	20	67
14	15.25	75	9.0	22.9	883	171	973	6	62	17	24
15	15.75	74	8.1	22.6	947	199	963	9	66	22	34
16	16.4	73	9.2	22.8	2062	472	3020	13	82	23	38
17	17.4	72	14.1	22.9	2583	856	5541	11	100	16	29
18	19.4	68	17.6	23.7	2094	1715	5828	18	105	30	35
19	19.9	69	18.4	23.8	2648	2316	6563	17	108	23	24
20	21.25	67	0.3	5.6	ND	ND	73	21	9	115	100
21	23.5	65	0.3	7.0	74	17	154	32	25	113	138

TABLE 5

CORE # WA20

	DEPTH	SPEC #	SUSC. (cgs.)	SAT. REM. (emu.)	SAT. REM.(200) (emu.)
1	0.4	17	35.90	88.70	24.70
2	1.8	16	53.50	132.90	46.10
3	2.25	15	12.84	37.10	5.18
4	5.4	14	22.19	68.90	10.90
5	6.3	13	23.35	72.10	14.64
6	7.4	12	24.10	112.20	31.60
7	8.4	10	42.87	154.40	90.30
8	9.4	9	26.95	96.60	16.87
9	11.3	11	27.81	123.50	11.88
10	12.4	8	31.80	98.80	35.20
11	13.4	6	16.87	66.40	14.30
12	14.4	7	17.41	95.40	23.00
13	15.4	1	22.80	76.00	33.20
14	16.7	5	0.71	2.87	1.06
15	17.4	3	0.18	1.18	0.65
16	18.4	18	25.78	130.70	26.07
17	20.4	2	0.24	4.86	4.12
18	22.4	4	0.23	2.02	1.06

TABLE 6

CORE # WA20

	DEPTH	SPEC #	A	B	C
1	0.4	17	3.18	-0.43	0.19
2	1.8	16	3.43	-0.43	0.23
3	2.25	15	2.60	-0.39	0.11
4	5.4	14	2.96	-0.36	
5	6.3	13	2.99	-0.37	
6	7.4	12	3.13	-0.24	0.10
7	8.4	10	3.41	-0.32	
8	9.4	9	3.12	-0.32	0.10
9	11.3	11	3.21	-0.26	0.07
10	12.4	8	3.18	-0.37	0.06
11	13.4	6	2.86	-0.29	
12	14.4	7	2.98	-0.19	0.10
13	15.4	1	3.00	-0.34	
14	16.7	5	0.93	-0.28	
15	17.4	3	0.23	-0.13	0.39
16	18.4	18	3.21	-0.21	
17	20.4	2	0.75	+0.22	0.48
18	22.4	4	0.47	-0.04	0.49

A = OXIDE CONTENT PARAMETER
= APPROXIMATELY EQUAL TO DISTANCE OF POINT FROM THE ORIGIN

B = OXIDE GRAIN SIZE PARAMETER
= PERPENDICULAR DISTANCE OF POINT FROM 45 DEGREE LINE PASSING THROUGH ORIGIN

C = Fe^{2+} / Fe TOTAL

TABLE 7

CORE # WA20

	DEPTH	SPEC #	MED GRAIN	CLAY	SILT	SAND
			I- PHI -I	I------	PERCENT	--------I
1	0.4	17	3.65	2.9	31.3	65.8
2	1.8	16	3.91	4.8	26.6	68.6
3	2.25	15	3.71	0.4	29.2	70.4
4	5.4	14	3.62	0.4	26.8	72.8
5	6.3	13	4.03	0.2	32.6	67.0
6	7.4	12	3.83	0.1	34.7	65.1
7	8.4	10	3.73	0.1	33.4	66.5
8	9.4	9	4.19	1.8	48.0	50.2
9	11.3	11	4.09	0.7	51.6	47.7
10	12.4	8	4.29	0.6	38.0	61.4
11	13.4	6	3.60	2.0	31.8	66.2
12	14.4	7	3.68	1.3	37.0	61.7
13	15.4	1	3.95	2.7	45.1	52.1
14	16.7	5	7.80	43.4	55.3	1.3
15	17.4	3	8.91	67.2	32.1	0.7
16	18.4	18	4.38	0.4	64.9	34.7
17	20.4	2	9.10	74.1	24.0	1.9
18	22.4	4	6.89	43.9	45.2	0.9

TABLE 8

CORE # WA20

	DEPTH	SPEC#	S	Fe	Cu	Pb	Zn	Ni	Co	Cr	V
			I--- % ---I		I---------- ppm. ----------I						
1	0.4	17	33.6	31.8	636	747	1057	3	35	2	41
2	1.8	16	34.5	27.3	397	726	1368	3	31	5	41
3	2.25	15	12.6	23.7	5182	293	1215	18	198	19	22
4	5.4	14	12.0	27.1	3482	417	2025	14	70	11	26
5	6.3	13	13.6	28.6	2631	454	1834	7	68	13	19
6	7.4	12	5.4	22.9	1234	206	915	23	50	52	90
7	8.4	10	7.9	23.9	2157	490	2523	14	68	25	42
8	9.4	9	22.2	29.7	2988	6212	5743	27	111	25	13
9	11.3	11	27.7	33.5	2005	1	10139	18	124	14	1
10	12.4	8	25.7	32.7	3319	1	7433	29	132	29	1
11	13.4	6	19.8	27.5	2722	551	2362	14	71	14	50
12	14.4	7	20.5	27.9	1967	12856	9490	14	113	9	13
13	15.4	1	25.4	31.5	3998	1	6020	19	127	10	7
14	16.7	5	0.6	8.4	77	31	231	38	28	134	110
15	17.4	3	0.1	8.3	40	19	101	52	30	163	120
16	18.4	18	15.9	28.4	2413	385	4305	12	84	14	13
17	20.4	2	0.1	7.5	32	17	81	51	30	155	106
18	22.4	4	0.1	7.8	32	19	87	53	26	139	122

TABLE 9

CORE # WA22

	DEPTH	SPEC #	SUSC. (cgs.)	SAT. REM. (emu.)	SAT. REM.(200) (emu.)
1	0.4	30	10.93	37.30	3.99
2	1.4	31	3.60	35.60	12.94
3	2.4	29	8.61	25.10	2.78
4	3.4	28	8.55	26.60	2.60
5	4.4	27	7.47	27.30	3.24
6	5.6	25	10.20	31.90	2.31
7	6.4	24	8.68	29.50	11.60
8	7.4	26	15.51	71.40	15.28
9	8.4	23	15.97	69.70	6.62
10	9.4	22	16.81	63.40	9.52
11	10.4	21	16.73	52.80	9.81
12	11.4	20	15.98	68.10	11.03
13	12.4	19	19.50	75.50	22.50
14	21.4	38	28.65	93.70	42.14
15	24.4	37	28.98	187.30	41.53
16	25.4	36	15.46	72.90	25.20
17	26.4	34	20.29	88.00	28.50
18	27.4	35	21.95	108.20	41.40
19	28.4	39	31.04	142.40	51.10
20	29.4	32	21.61	109.60	23.40
21	30.4	33	21.83	86.70	30.80
22	31.4	31'	19.52	113.10	38.02
23	33.4	33'	17.28	114.10	26.52
24	34.4	34'	20.42	134.90	60.70
25	35.4	35'	17.66	142.30	43.40

TABLE 10

CORE # WA22

	DEPTH	SPEC #	A	B
1	0.4	30	2.55	-0.33
2	1.4	31	2.20	-0.08
3	2.4	29	2.36	-0.38
4	3.4	28	2.37	-0.36
5	4.4	27	2.34	-0.31
6	5.6	25	2.48	-0.36
7	6.4	24	2.41	-0.33
8	7.4	26	2.86	-0.24
9	8.4	23	2.86	-0.26
10	9.4	22	2.85	-0.30
11	10.4	21	2.79	-0.36
12	11.4	20	2.85	-0.27
13	12.4	19	2.95	-0.30
14	21.4	38	3.13	-0.35
15	24.4	37	3.35	-0.14
16	25.4	36	2.86	-0.24
17	26.4	34	3.01	-0.26
18	27.4	35	3.09	-0.22
19	28.4	39	3.28	-0.25
20	29.4	32	3.09	-0.21
21	30.4	33	3.02	-0.29
22	31.4	31'	3.07	-0.17
23	33.4	33'	3.04	-0.13
24	34.4	34'	3.14	-0.13
25	35.4	35'	3.11	-0.07

A = OXIDE CONTENT PARAMETER
= APPROXIMATELY EQUAL TO DISTANCE OF POINT FROM THE ORIGIN

B = OXIDE GRAIN SIZE PARAMETER
= PERPENDICULAR DISTANCE OF POINT FROM 45 DEGREE LINE PASSING THROUGH ORIGIN

TABLE 11

CORE # WA22

	DEPTH	SPEC #	MED GRAIN	CLAY	SILT	SAND
			I- PHI -I	I------	PERCENT	--------I
1	0.4	30	3.88	3.0	37.2	59.8
2	1.4	31	5.25	0.2	78.2	21.6
3	2.4	29	4.07	0.7	38.5	61.8
4	3.4	28	4.10	2.2	39.6	58.2
5	4.4	27	3.53	0.3	25.2	74.5
6	5.6	25	3.68	1.2	32.8	66.0
7	6.4	24	3.62	2.5	31.1	66.4
8	7.4	26	4.95	0.0	76.2	23.8
9	8.4	23	3.95	3.7	38.4	57.9
10	9.4	22	3.16	2.6	18.2	79.2
11	10.4	21	3.09	1.3	17.5	81.8
12	11.4	20	3.46	1.8	31.1	67.1
13	12.4	19	3.52	3.5	28.8	67.7
14	21.4	38	3.38	2.3	22.3	75.4
15	24.4	37	4.24	1.8	51.5	47.7
16	25.4	36	4.72	2.2	67.4	30.4
17	26.4	34	4.18	2.5	46.8	50.7
18	27.4	35	3.70	1.4	40.3	58.3
19	28.4	39	3.92	0.4	40.6	58.0
20	29.4	32	3.83	2.1	45.0	52.9
21	30.4	33	3.91	2.0	45.7	52.3
22	31.4	31'	4.75	2.6	61.4	36.0
23	33.4	33'	3.64	1.0	53.5	45.5
24	34.4	34'	4.16	0.2	63.9	35.9
25	35.4	35'	4.20	2.3	56.7	41.0

TABLE 12

CORE # WA22

	DEPTH	SPEC#	S	Fe	Cu	Pb	Zn	Ni	Co	Cr	V
			I-- %	---I	I---------		ppm.			----------I	
1	0.4	30	3.8	17.8	406	72	284	22	29	79	142
2	1.4	31	15.8	22.1	5507	798	999	43	81	59	77
3	2.4	29	11.3	21.7	969	218	1489	59	75	81	84
4	3.4	28	13.9	22.8	1029	235	1029	68	58	68	69
5	4.4	27	12.2	21.3	1019	157	2384	59	55	67	74
6	5.6	25	11.4	21.5	1333	275	2812	53	61	54	75
7	6.4	24	10.0	20.8	1304	316	1590	34	48	56	100
8	7.4	26	4.8	21.5	814	130	1259	29	51	67	92
9	8.4	23	5.7	21.7	1557	163	1557	20	53	45	88
10	9.4	22	7.1	20.2	2534	204	1218	20	50	55	80
11	10.4	21	5.2	18.7	1843	142	1124	20	43	54	103
12	11.4	20	5.2	18.6	1006	202	1006	19	43	52	89
13	12.4	19	5.2	21.8	1153	178	937	21	52	45	85
14	21.4	38	5.2	25.4	3142	731	2469	11	73	13	33
15	24.4	37	8.4	23.6	2014	221	1553	12	54	22	51
16	25.4	36	10.0	22.0	1278	319	2619	10	69	23	34
17	26.4	34	13.9	23.7	2307	645	3268	11	98	10	29
18	27.4	35	18.3	27.3	2544	2006	4103	15	101	17	25
19	28.4	39	17.4	26.7	2972	2583	4574	17	102	12	15
20	29.4	32	13.6	23.3	2005	978	2005	16	95	26	41
21	30.4	33	20.6	26.6	2067	1888	4134	9	115	17	11
22	31.4	31'	18.3	30.2	1979	174	4562	18	119	25	12
23	33.4	33'	18.4	31.0	2913	568	4993	13	115	17	8
24	34.4	34'	14.3	26.3	1182	226	6208	20	104	30	24
25	35.4	35'	16.9	26.5	1475	257	7571	14	111	26	17